MAKING INFRASTRUCTURE VISIBLE: A CASE STUDY OF HOME NETWORKING

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MAKING INFRASTRUCTURE VISIBLE: A CASE STUDY OF HOME NETWORKING

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To my family, for their utmost love and support

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SUMMARY

Technological infrastructure is often taken for granted in our day to day lives until it breaks down, usually because it invisibly supports tasks otherwise. Previous work in HCI has focused on how people react and deal with breaks in infrastructure as well as how to help people to fix or exploit these breaks. However, few have sought to understand how people will react to information about infrastructure when it is functioning normally or whether access to this information causes changes in how people engage with that infrastructure. The goal of my dissertation is to understand how people's engagement with infrastructure changes when they are provided with information about that infrastructures normal functioning, i.e., when this oftentimes invisible information is made visible.

To achieve this goal, my chosen case study of infrastructure is the home network, a self-contained socio-technical system within the domestic space. Much like other infrastructures, the home network suffers from visibility issues when it is functioning properly or even when it breaks even though it has a distinct digital footprint—the collection of information about traffic between devices on the home network as well as information about the devices comprising the network. The digital footprint not only contains information about network use but it also reflects computing routines or everyday household activities and policies around the network, such as what resources the network uses (e.g., bandwidth or electricity) or who is using the network, when and for how long.

The home network is an interesting case study because the digital footprint is still largely inaccessible to household occupants for four reasons. First, networked domestic technologies have become increasingly common and oftentimes are being

integrated directly into the home's built environment. For instance, Ethernet cabling may be built into new homes, and in the event that connections are not working, this problem may be impossible to troubleshoot without tearing up walls. Other times, technologies may be totally wireless and difficult to visually assess for problems. Second, the devices making up the home network are distributed throughout the home making it hard to gather an overview of the network topology or configuration in one place. Third, many of the devices making up the home network have reduced interfaces such as a series of blinking lights which provide little information, particularly when problems occur. Fourth, even when tools exist to access glimpses of the digital footprint, such as network traffic visualizers, these are accessible and known only to the most technically able household occupants. Often, these technical occupants know where to look for this information and what to do with it when they get it, e.g., using "ping" to determine if the network is working.

In all, these issues make it difficult to understand who is contributing to the digital footprint at any one time. It also remains unclear how we can use this information as a point of reflection on computing routines (e.g., how is the network used and what resources does it require) or for broader maintenance purposes such as troubleshooting the devices making up this network. In this dissertation, my aim has been to investigate how surfacing the invisible in the home can affect users' engagement with infrastructure. The document is structured as follows. I first describe the motivation for this work and previous related work on infrastructure and visibility. I then provide background information on my chosen case study, home networks, and discuss how the digital footprint has evolved over time. Next, I describe how the digital footprint remains largely invisible and the opportunities that exist for surfacing this information. I also describe the user-centered design approach I followed. Thereafter, I detail the empirical results that have informed my design of the Kermit system, the technology probe I used to surface aspects of the home's digital footprint. I implemented Kermit to determine how householders react to information about their home networking infrastructure when it is functioning normally. My aim was to determine whether this changes their engagement with that infrastructure. I describe the detailed design and requirements for Kermit and the pilot study and final field trial conducted in Spring 2010. I then discuss themes from the entire body of work and design considerations for making infrastructure visible, a concept I call inspectability. Finally, I summarize my overall contributions and suggest future research directions for achieving inspectability in the home via another concept I introduce called network- mediated sensing. I conclude that my research suggests making infrastructure more visible has benefits for helping users manage these complex systems of systems.

CHAPTER I

INTRODUCTION

Infrastructure refers to the substrates, frameworks and building blocks that underpin and support our daily lives [91]. For example, infrastructure may refer to physical elements such as electricity grids, roads and buildings, or to social mechanisms such as organizational hierarchies or technological artifacts such as software or appliances. For the most part, technological infrastructure is often taken for granted in our day to day lives until it breaks down, usually because it invisibly supports tasks otherwise. Previous work in HCI has focused on how people react and deal with breaks in infrastructure as well as how to help people to fix or exploit these breaks [4, 5]. However, few have sought to understand how people will react to information about how an infrastructure is functioning in real-time or whether access to this information causes changes in how people engage or perceive that infrastructure, particularly in the domestic space. Yet, breakdowns in infrastructure, especially in the home, can cause headaches as users seek to make their technologies work [40]. My research goal has been to understand how people's engagement with infrastructure changes when they are provided with information about how they are using that infrastructure on a day to day basis, whether or not is it breaking down, i.e., when this oftentimes invisible information is made visible. My aim has been to improve the end-user experience of domestic infrastructures in doing so, and to derive design implications for tools that make infrastructure more visible in general.

Arguably, making information about how infrastructure technologies work more visible improves intelligibility and usability and opens up opportunities for reflection [25, 34, 35, 80, 84]. For example, helping people understand how a system works or why it takes a particular action can help them better use the system for their needs. Researchers have argued, for instance, that a smart home's automated systems may not be able to "do the right thing" even when the system action required seems logical. For instance, adjusting the temperature in a home by opening blinds may upset someone working at a computer, when the glare hits the screen [49]. This kind of error might be avoided in future if the system displayed why it was taking a particular action, for example, showing the user it has opened the blinds because it has concluded the temperature is too low for the occupants. The occupant could then adjust the settings to exclude the office from having the blinds opened during working hours.

Similarly, when users create folk theories about how devices work, such as with thermostats [52], they can use a system inefficiently. If they form an incorrect mental model of a thermostat—believing, for example, that turning up the temperature heats the home more quickly—they may set their thermostats too high. In this situation, having visibility into how the thermostat adjusts temperature or a measure of the temperature and the rate of change may help participants form a better mental model of the system and help them to optimize their settings. The literature therefore suggests that obscure and often invisible technological infrastructure can cause complications in everyday use. Moreover, making certain aspects of infrastructure more visible could help users understand and manage their infrastructures more easily, with the caveat that the information should only be available when needed and not overwhelming.

To investigate the theory behind this reasoning, in my dissertation, I chose to develop a system to show home users how their home infrastructure is being used on a day to day basis. My goal was to see if this information helps them understand and manage these building blocks more effectively. I engaged in this research to determine whether making the invisible supporting frameworks or infrastructure in the home more visible actually increases people's engagement with their infrastructure. I wanted to explore whether this process has implications for technology adoption, appropriation as well as the sense of self-efficacy people feel with respect to their infrastructure—that is the perception of one's own level of competence with respect to operating, maintaining and troubleshooting technologies.

To achieve my goal, I chose to study an infrastructure that is fast becoming standard in homes, particularly in the U.S.—the home network. A home network is essentially a self-contained socio-technical system within the domestic space and makes for an ideal case study of infrastructure. The network is socio-technical because it depends on both people to make it work and on technologies to create the functionality required for Internet connectivity. Essentially, home networks are comprised of computers, modems, routers, televisions, media centers, set top boxes and the cables and wires (and in some instances, wireless streams) to connect them. Managing this complex home network or series of devices and all the connections needed to make them interact with one another and the outside world is a task that requires multiple home occupants to coordinate [40]. For example, even a task as seemingly simple as giving a friend access to a home's wireless network requires knowledge of the network name, possibly a password and knowledge of how to input these parameters into the wireless management system on a personal or mobile computer. Home networks require resources other than time, coordination and effort. Each device on the network also consumes electricity and usage times of devices are reflective of the rhythms of a home such as low activity periods when people are generally at work or asleep.

Much like other infrastructures, every home network also suffers from visibility issues. Yet, each home network is a wealth of information, with a distinct ever-changing ***digital footprint***—the collection of information about traffic between devices on the network as well as information about the devices themselves. This digital footprint is, in real-time, reflecting masses of information about the household's life including the rhythms of the home, such as when people are using the network or are at home, resources the network uses, such as time spent online or about the occupants, such as who is online and what they are doing online.

Despite this wealth of information being generated minute-by-minute in the home, a home's digital footprint is still largely inaccessible to household occupants for several reasons. First, networked domestic technologies have become increasingly common and oftentimes are being integrated directly into the homes built environment. For example, Ethernet cabling may be built into new homes, making it harder to find out why connections are not working without tearing up walls [17]. For example, if an Ethernet cable coming through the walls is not working, it is difficult to quickly determine if the fault is with the cable or the devices the cable is connecting. A light indicating whether a cable is faulty or not could augment existing lights that show whether a port is working to better aid users with this problem. With wireless technologies, visibility is further compromised because the traffic flowing through the network is not obvious to the naked eye, nor are its boundaries. In my earlier work described in Chetty et al. [17] and Chapter 3, I found that users were often confused about where their wireless networks extended to or whether users who were not authorized to use the network were trespassing. Second, the devices making up the home network are distributed throughout the home (or sometimes hidden for aesthetic purposes) making it difficult to gather an overview of the network topology or configuration in one place. In my formative work, I found that people had to create visual representations to help them recall how many devices they had and how they were configured.

Third, many of the devices making up the home network have reduced interfaces with a series of blinking lights which provide little information, particularly when problems occur. For instance, glancing at a router does not immediately tell you who is online or if the network has been compromised. Fourth, even when tools exist to access glimpses of the digital footprint, such as network traffic visualizers, these are accessible and known only to the most technically able household occupants. Often, these occupants know where to look for this information and what to do with it when they get it, e.g., using "ping" [48] to determine if the network is working. Frequently, the relative invisibility of the digital footprint can lead to problems with home network maintenance, communication about networking problems and understanding how the network is using resources (e.g., bandwidth). More importantly, for the everyday home occupant, often this kind of invisibility leads to frustration as end-users try to figure out more about their networks from this series of reduced interfaces and different devices [44].

In my dissertation, my goal was to understand more about what visibility issues around the digital footprint of the household exist. Further, I sought to understand whether surfacing parts of the digital footprint around computing routines as well as associated resources causes people to engage differently with home networking infrastructure. For example, I envisioned that altered engagement could include getting users to participate more actively in problem solving. Other effects I envisioned were that users may experience changes in their sense of self-efficacy with technology or increase their understanding of the computing routines of the home and the resources these use (e.g., bandwidth)—all through gaining access to their home's digital footprint in terms they can understand as opposed to networking arcana.

My contributions are to expose home networking empirically, and to showcase the joys and sorrows that users experience as they fumble with their networking equipment. In exposing their troubles, and also their routines around the home network, I also seek to showcase how rich the digital footprint is. Aside from empirical evidence of the pains of home networking, I contribute a prototype tool for giving people a window into their digital footprint, in my case, to understand why their Internet connections are running slow. Through evaluating the prototype, I provide evidence that exposing the digital footprint to users even minimally can change how they view and use their infrastructure. Based on my results, I discuss overall themes emerging from this body of research and introduce the concept of ***inspectability***—making infrastructure visible—along with design considerations for achieving inspectable interfaces. Finally, I provide future directions for research such as how to implement inspectability in the home via ***network-mediated sensing*** and I draw overall conclusions. Next, I present my thesis statement and research questions.

1.1 Purpose of Research and Thesis Statement

Surfacing aspects of the home's digital footprint—the information contained within and about a home network which is largely invisible—will cause changes in user engagement with home networking infrastructure and computing routines. Specifically, changes in user engagement may include changes in householders' levels of self-efficacy with technology or the understanding of how computing routines use resources such as electricity, time and bandwidth. Changes in user engagement caused by increased visibility will have implications for the design of infrastructure technologies and the systems we use to help us maintain them.

1.2 Research Questions and Approach

My research questions are:

- RQ1: What visibility issues around the home network emerge from studies of households' engagement with networking infrastructure, and which of these are exacerbated by the lack of a visible digital footprint?
- RQ2: How do households perceive their computing routines and the resources they use for engagement with home networking infrastructure, and how much of this is visible through the digital footprint?

- RQ3: How will surfacing invisible aspects of the digital footprint cause changes in households' engagement with home networking infrastructure? Specifically, will the following user engagements change as a result of interactions with Kermit, a technology probe for surfacing aspects of the digital footprint based on findings from RQ1 and RQ2:
  - RQ3.1: Change users sense of self-efficacy with respect to the home network
  - RQ3.2: Change computing routines and the awareness of resources users use

    e.g., through increased problem solving, increased awareness of bandwidth, time spent on computing routines or via other emergent behaviors

To answer these questions, I conducted the following research using a user-centered design approach [24], a summary of which is provided in Table 1.

RQ1: First to answer RQ1, I sought to understand what visibility issues exist around the home network and how these are exacerbated by a mostly invisible digital footprint. Therefore, I conducted two empirical studies of how people manage, troubleshoot, and maintain their home networks. I studied various types of households including families with children, couples, and roommates. I investigated how they conceive of their home networking infrastructure, what tools they use to do so and how they collectively manage their networks. I also determined how devices enter and leave the home network. For these studies, which took place in Atlanta, GA in the U.S., I used a variety of qualitative techniques—interviews, home visits, surveys, user sketches, and technology inventories.

RQ2: Second, to answer RQ2, I wanted to understand how users perceive their routines and the resources they use when dealing with home networking infrastructure. I also wanted to know how much of this is visible through the digital footprint.

Table 1: Summary of Thesis Studies.

Research Question	Studies Completed	Outcomes
RQ1	Formative studies of households about home network usage completed in Spring 2006 and Fall 2007. Consisted of interviews, surveys, and home visits with 26 households in Atlanta, GA, U.S..	Resulted in [17] and the related publication [86] Described in Chapter 3.
RQ2	Formative studies of home computer usage completed in Summer 2008. Consisted of interviews, surveys and quantitative logs of computer use with 20 households in Seattle, WA, U.S.	Resulted in [15] and the related publication [18]. Described in Chapter 4.
RQ3	Kermit probe design, implementation and field trial completed in Spring 2010. Evaluated using interviews, surveys, logs of use, and home visits with 10 households in Atlanta, GA, U.S.	Resulted in [16] and the related publication [14]. Described in Chapter 5.

Thus, I studied family households in Seattle, WA in the U.S. to understand more about resources that the network requires as well as how aware users are of these everyday rhythms and resources. To do so, I used a combination of qualitative and quantitative techniques. I conducted home visits, and used logging software to track all the activity on every home computer in the participating households. Although, I did not log network events in this study, I believe logging computer usage and visualizing this information provided sufficient insights into how users conceptualize their computing time in particular.

RQ3: Finally, to answer RQ3, based on my results from these three empirical studies, I derived design implications for a home network visualization probe. I implemented this probe, called Kermit, to show household occupants one salient aspect of the digital footprint—why is the Internet slowing down—a theme which had emerged from my formative studies. I evaluated Kermit with households in

Atlanta, GA in the U.S. using a mixed methods approach—interviews, home visits, logs of software use, surveys, and sketches.

Overall, my results comprise a rich description of how households use and maintain their home networks and how they conceive of their digital footprint. I also learned through the evaluation of Kermit, how to surface aspects of the digital footprint in ways that cause changes in engagement in infrastructure. I discuss each of these studies, the methods used and the results in more detail in the following chapters. My contributions are:

1. Empirical evidence of the travails of home networking
2. A novel broadband management proof-of-concept prototype
3. Design considerations for making infrastructure visible under the concept of inspectability
4. Future research ideas for implementing inspectability via network-mediated sensing in the home

Next, I outline several topics that are beyond the scope of my work and left for future studies.

1.3 Beyond the Scope of This Dissertation

My dissertation focus was scoped to make it tractable within the thesis timeline. I mention these areas of research to indicate that they are important considerations and aspects of my chosen problem but that they are left for future work:

- Adoption issues around systems which surface information about infrastructure: In this dissertation, I focused only on whether increased visibility leads to changes in engagement with infrastructure. I wanted to understand how those changes can be used to affect technology adoption, appropriation and perceptions of self-efficacy with technology as well as technology design. I see adoption as related to how often users use a particular system and how well they integrate it into their daily routines. By contrast, I view engagement as the ways in which users utilize a particular system or in which that system affects their routines around a particular infrastructure.

- The presentation of information more closely: Since network information is largely invisible at present, I have looked to information visualization for inspiration about how to initially present aspects of the digital footprint around computing routines and resources. However, a full investigation of how the way the information is presented affects engagement is left for future work.

- Other home infrastructures such as electricity or plumbing: These infrastructures could also reveal household routines to users but are much less interesting because they do not have personal occupant information flowing through them in the same way as the home network. Again, future projects might examine how to show people patterns in their resource consumption in these other infrastructures and other work has shown this may be a fruitful direction [85].

- Creating better home network troubleshooting or maintenance tools: In this dissertation, I cast my net more broadly than a focus on troubleshooting alone. Clearly, breaks in infrastructure are important for helping users fix problems as they arise but my focus is also on perceptions of the home network and users' sense of self-efficacy with technology.

- Surfacing other aspects of the digital footprint: I focused my investigations on information related to the topic of why the Internet is slowing down in a home. The digital footprint is vast and rich and many different visualizations could be created to show homes more about their home network habits. In future work, I will explore other aspects of the digital footprint, that may reveal other information about participants, particularly in combination with other sensors. For example, studies could create visualizations that focus on sustainability and power usage using information from the digital footprint or power meters.

1.4 Overview of Dissertation

The remainder of my dissertation document is structured as follows. In Chapter 2, I first describe the motivation for my work and previous related work on infrastructure and visibility. I then provide background information on my chosen case study, home networks, and discuss how networks have evolved over time. Next, I describe how the digital footprint remains largely invisible and the opportunities that exist for surfacing aspects of this rich source of information to affect user engagement. I also briefly describe the user-centered design approach I followed with the use of a technology probe.

Thereafter, in Chapter 3 and 4, I detail my empirical studies, methods and results of households in Atlanta and Seattle respectively. I also draw out implications to show how these studies informed my design of Kermit. Kermit is a technology probe that I created for surfacing aspects of home's digital footprint. In Chapter 5, I describe the detailed design and requirements for Kermit and the pilot study and system evaluation. Through evaluating Kermit, I examined how householders react to seeing parts of their digital footprint in terms they understand and how this changed how they used the home network. In Chapter 6, I discuss the overall picture I formed from the collective body of dissertation work including the introduction of the term inspectability as well as design considerations for inspectable systems. I then step back and reflect on the various components of HCI that my dissertation research contributes to in Chapter 7. Finally, I conclude with a summary of my contributions and suggestions for future work such as considerations for implementing inspectability in the home via network-mediated sensing in Chapter 8.

CHAPTER II

RELATED WORK

In this chapter, I first describe how infrastructure suffers from transparency issues. Next, I present examples of how researchers have attempted to improve system intelligibility, accountability and usability for infrastructure technologies. Moreover, I identify gaps in the literature which my research addresses, such as revealing technological infrastructures to users in real-time to determine how that affects how they use and perceive those digital substrates. Thereafter, I describe the domestic literature around my chosen case study of infrastructure—home networks—and describe why these networks constitute infrastructure. I then specifically describe the challenges of visibility from which home networks suffer. Moreover, I explain how the digital footprint—the information flowing through the home network, as it is being used as well as the information about the devices connected to the network—is currently largely invisible to household occupants.

Thereafter, I describe previous approaches to surfacing the digital footprint and how my own approach contributes to our understanding of making technological infrastructures more usable. I also provide an overview of the aspect of the digital footprint I have chosen to surface—network speed and bandwidth information. In particular, I explain why this information is important for users and how it may affect their engagement with infrastructure. As mentioned in Chapter 1, in my dissertation, I have begun my exploratory investigation into making technological infrastructures more visible by scoping the information about what I reveal to a small section of the digital footprint. Further explorations are left for future work and discussed in Chapter 6 and Chapter 8.

2.1 Infrastructure and Visibility

Infrastructure constitutes physical, digital, and social substrates which underpin and support our daily activities [91]. It can comprise anything from roads, electricity grids to software and social processes. Most importantly, it is an often taken for granted part of everyday life until it breaks, as Star and others have commented [11, 76, 77, 91, 92]. Yet a close examination of infrastructure can reflect contemporary socio-technical trends. For instance, in standard classification forms the fact that there are no options for reflecting same-sex partnerships under marital status is indicative of how our society perceives these relationships [11].

Examining infrastructure can also influence technology design. Consider, for a moment, the home where the evolving nature of the physical structure and the belongings we have in them affect how we create devices, appliances, and networks to fit into this architecture [12,76,77]. For example, household arrangements such as rooms and furniture or even walls may not be stable over a long period of time. Household members may redecorate a home or renovate, causing changes to the physical layout. As designers, we therefore need to account for temporal changes in a home's infrastructure to determine how the technologies we design fit into an ever evolving environment.

Because of the relative invisibility of infrastructure, to properly examine how it shapes our lives, we have to engage in "infrastructural inversion" or fight against tendency of networked infrastructure to disappear in use [11]. One way to do so is to reflect on when there are breakdowns in infrastructure at which point the technological substrates we use daily become visible. For example, when an Internet connection goes down, home Internet users are then aware of the network connecting them to the Internet as they seek to fix the problem.

Already, HCI researchers have examined and considered what happens when there are breaks in infrastructure [26]. Several researchers demonstrated how people react to or exploit these breaks—for example in mobile real-world games, participants exploit breaks in wireless networking to play the game more effectively [4]. Others have worked to improve the visibility of infrastructure and technology systems to improve overall system usability. Specifically, previous work has suggested that systems which help users understand why a system is behaving in a particular way can improve overall system intelligibility (i.e., showing users how the system reached its goal and why it is undertaking particular actions), accountability (i.e., showing users what the system knows about them especially when their data is visible to other users) and usability (i.e., general ease of use) [5, 25, 27].

In fact, systems which are black-box in nature can often lead to users to form incorrect theories about how they work. For example, one study showed how users often do not realize how a thermostat works. In this experiment, users were setting their thermostats to the highest or lowest settings because of assumptions that turning the dial up or down caused the room to heat or cool more quickly [52]. Another way then to engage in "infrastructural inversion" could be to show users how technological infrastructure is being used in real-time, whether or not it is functioning properly.

Yet few have attempted to show users this type of information or to determine if this information affects how users engage with that infrastructure or if this type of visibility leads to improved intelligibility and usability. My dissertation fills this gap in the literature by providing empirical evidence of how making infrastructure more visible affects how users engage with that infrastructure.

2.2 Home Networks Case Study

I now turn to a description of my chosen case study: home networking infrastructure. I explain how home networks first entered the home and why they constitute an appropriate case study for examining visibility issues with infrastructure.

2.2.1 Evolving Domestic Networks

Computing devices first began to enter the domestic space several decades ago [98]. Along with the increase in domestic technologies, researchers sought to understand how homes were using and appropriating these technologies, examining everything from how household routines were affected to the use of these technologies themselves. Early HCI domestic research therefore had more of an applications focus. Some studied how occupants' routines structure domestic life and the resulting implications for technology design [9, 95]. For example, researchers found that the home's built environment or infrastructure, such as room layouts and configurations (e.g., wall sockets or walls), can play a role in establishing and maintaining routines.

Those focused on the use of technologies explored how devices such as set-top boxes [64] and VCRs [78] are used. These studies also highlighted how users tend to adopt technology based on how the product interacts with the broader contexts of the home (e.g., divisions of labor) [8]. At this point in time, technologies remained largely stand-alone devices, with little interconnections within the home and no connections from within the home to the outside world.

In the early nineties, households' access to information began to broaden beyond the home as Internet access began to spread. The research focus then shifted to understand how this network connection to the outside world influenced domestic activities. For instance, Kiesler et al. [54] first studied how people used and appropriated the Internet in the early 1990s. They found that people often relied on family, usually a teenager as well as technical support, to deal with networking problems related to connectivity. Others examined the blurred boundaries between work and play as telecommuting caused people to bring work into the home [98], with many households even going so far as to create home offices complete with supporting technologies.

Along with the changes in the home associated with the affordances of Internet connectivity, and the increasing possibilities when devices were not only connected to the Internet but to each other in the home, researchers started to created applications that leveraged this emerging domestic networked infrastructure [21]. Examples of such systems include CareNet, an ambient display for elderly health care [20] and in-home displays for increasing interpersonal awareness, such as the Digital Family Portrait (DFP) [81].

Other domestic systems were created for coordination (e.g., LINC the ink-able family calendar [63]) or to enhance family communication (e.g., HomeNote [82]). In these studies, networked infrastructure in the home began to emerge as a point of interest in terms of how and where technologies are used, and also in deployment challenges of dealing with a distributed infrastructure.

As technologies came home, households were beginning to develop many traces of activity on their computing devices. Along with devices being connected to the broader Internet, people started to connect up their devices to each other, creating home networks of computing and audio-visual devices such as computers, televisions, routers, modems and their connections such as Ethernet cabling and WiFi.

Some sought to study advanced home networking ahead of the adoption curve through the development of "smart homes" [42, 49, 53]. These were research homes designed with a host of technologies built in, to control everything from lighting, temperature as well as devices and appliances. These living labs served to further demonstrate the complexity of home networking. For example, these homes illustrated the significant effort needed to resolve problems with infrastructure [28], particularly with the absence of the office equivalent of administrative support and without a clear visualization of the corresponding digital footprint of all these networked technologies in the home.

Others studied how households naturally began to acquire these networks and the ways occupants appropriated and adopted this infrastructure [40]. I turn to a description of the results of these studies next. However, prior to discussing this related work, I first describe how this emergent domestic network constitutes a self-contained infrastructure system. This discussion explains why I chose home networking as a case study for my dissertation research.

2.2.2 Home Networks as Infrastructure

Home networks sit in line with Star's [91] definitions of the properties of infrastructure, as confirmed by many studies [8, 17, 40, 86, 97]. Star outlines several properties of infrastructures and here, I describe how home networking fits the defining characteristics she outlines in her paper [91]. Most importantly for my research, home networks are somewhat transparent, and they invisibly support networking tasks. Usually, these networks only become apparent to home occupants when they break, such as when the Internet connection goes down. At other times, routers, modems and other critical pieces of wiring are often ignored. Home networks also display other fundamental infrastructure characteristics. For example, they have a degree of embeddedness in that they are setup, maintained and depend on the orchestration of stakeholders within and external to the home, such as household members, Internet Service Providers (ISPs) and cable companies [76, 77].

Further, these domestic networks are subject to rules defined by social structures and arrangements external to the home. For instance, ISPs in the U.S. are debating about introducing consumer bandwidth caps, an arrangement outside the home that nevertheless influences network usage within it [19]. Home networks also have spatial reach beyond one single device and like other infrastructures, are shaped by conventions of practice (e.g., how to connect to the network is determined by physical and wireless connections) as well as standards, such as how the basic networking stack is defined [85]. Like other infrastructures, networking infrastructure may be retrofitted into old homes or built into an installed base. Even when networking is built into new homes, the last-mile connectivity relies on existing cable and telephone infrastructure [17]. Finally, home networks evolve in modular increments as devices are added and removed from the network over time, much like other infrastructures [28].

Because home networks are fundamentally infrastructure technologies, they are subject to the same drawbacks as other infrastructures. As I mentioned before, the relative invisibility of home networking infrastructure (because of wireless technologies, wires built into walls, distributed devices and configurations) makes it difficult to manage, engage with and troubleshoot these networks [17]. Arguably, the invisible nature of home networks often leads to degradation in system intelligibility, such as when householders may not realize that their Internet connection has gone down due to an ISP error and not a router problem. Other consequences of invisibility of information in the home network include not being able to pinpoint the origin of a problem within the network (e.g., Is it my equipment that is faulty?) or knowing how much of the home's broadband connection cap a household has used [19].

Yet, this information is available in the form of the digital footprint as defined in Chapter 1. The digital footprint also contains information about the computing routines in the household (such as when and how the network is being used) and on the resources these routines require in terms of bandwidth and electricity.

With the emergence of the home network and this growing digital footprint, problems began to emerge around managing this burgeoning slew of devices. Consequently, researchers began to investigate how households were dealing with these issues. For example, studies found that most households living in old housing stock have to retrofit existing infrastructure to network their devices and others struggle to troubleshoot networked applications and devices, particularly when they lack the technical knowledge to do so [17, 40, 54, 85]. Further, because multiple stakeholders maintain and manage network services to the home (e.g., cable companies, ISPs and the home occupants) and the fact that the home's built environment is continuously evolving, network troubleshooting is further complicated [76, 77]. Even when homes have technically knowledgeable occupants, because of the inaccessibility of the digital footprint, managing the configuration of multiple devices and remembering device locations and state prove troublesome. Often because of the imprecision of determining where problems in networking arise, the simplest solution people follow is 'reboot, reset' or they may give up altogether, even returning equipment to the store [8].

Sometimes, adding to the invisibility problem, users may forget that certain devices are even still connected to the network because they are placed out of sight to maintain aesthetics [17]. Other researchers have found that in response to the difficulties of home networking, some people create visual reminders such as Visio diagrams, post-it notes, and instructions to help them understand and manage their networks [17, 97]. Often these aids, although containing bits of information about the overall digital footprint, are of limited usefulness because they are not all in one place and they are static [39]. And yet, home networks and their associated problems are growing. For instance as recently as 2008, the Pew Internet Group [44] reported that people become frustrated when they experience home networking failures. Therefore, determining how to surface the digital footprint in ways that make computing routines visible to householders and how that affects their engagement with the home networking infrastructure is a topic worthwhile of exploration.

Some have proposed directions for improving home networking, such as the "Outsource Model" or outsourcing network troubleshooting to professionals (e.g., Geek-Squad [37]) or the "Bandage Model" which makes suggestions on how to deal with currently available infrastructure (e.g., through creating home network visual systems) [85]. My dissertation research has focused on surfacing invisible aspects of the digital footprint that speak to computing routines and the resources these routines require. Specifically, I focus on the issue of network speed and bandwidth information. In the next section, I outline why this aspect of the digital footprint is of interest to end-users and how it may affect their engagement with their home networks.

2.2.3 Network Speeds and Visibility

Recently, not only is managing the home network a challenge as I have discussed, but increased Internet congestion means that households also have to deal with varying, and often slow broadband speeds. Slow speeds can be detrimental for the overall Internet experience, with 2 Mbps barely sufficient for TV quality streaming media [2, 68]. Speed slowdowns can be caused by factors internal and external to the household [74,99]. Internal factors can include bandwidth intensive applications choking a connection, old computing equipment causing stalls or multiple people using the Internet simultaneously creating bottlenecks. External factors can include the access technology itself (e.g., cable) only allowing for a maximum speed, ISPs shaping Internet traffic (i.e., controlling network packets to optimize performance) or peak usage times when most consumers get online. With a myriad of factors involved, deciding why a connection might be slow is complicated. Moreover, inherently limited last-mile access technology, network congestion and traffic shaping, mean speed variances are likely to persist [23, 74].

In fact, the gap between actual and advertised speeds is large, with overall speeds attained in the U.S. being quite low relative to other countries. To help improve offerings, in the recent National Broadband plan, the Federal Communications Commission (FCC) outlined minimum download speeds of 100 Mbps and upload speeds of 50 Mbps for all American broadband users [32]. Faster speeds mean that more users can experience the bandwidth intensive media that is beginning to dominate the network. Because of speed variances, certain governmental regulatory bodies such as Ofcom in the UK and the FCC in the U.S. have criticized providers for so-called “headline” speeds in their broadband package offerings. Mostly, the concern is that the wording in advertisements for broadband packages “up to” (e.g., “up to 1.5

Mbps") does not alert consumers that they may not attain those speeds consistently, or at all [65].

Amidst concerns over a minimum broadband speed for all, in the U.S. and elsewhere, deliberations about creating tiers of Internet service continue [99]. These net neutrality discussions (summarized by Jordan [51]), revolve around whether all Internet traffic should be treated equally, regardless of where it is from, where it is going or its content. Proponents of net neutrality argue that a tiered Internet with slow and fast speeds would create a new type of digital divide. Opponents of net neutrality argue that tiered Internet will guarantee a reasonable quality of service for real-time applications and ensure that content providers are not "free riding" on infrastructure maintained by ISPs. Already violations of net neutrality have occurred, notably with the case of Comcast, a U.S. ISP found to be shaping Bit Torrent traffic in 2007 [50]. In the most recent debates, consumer groups (such as moveon.org [61] and Free Press [33]) challenged the FCC for only considering big business viewpoints such as net neutrality supporters, Google and Microsoft and opponents, Comcast and AT&T [41]. For consumers, concerns include costs falling on them, high bandwidth users being penalized, and access to certain sites being limited because of additional fees.

With these broadband debates raging on and speed variances, the need for users to be more informed is clear. Yet, there is little data on whether users are aware of the broadband issues at hand, their connection speeds, or factors influencing their Internet experience. This is why I chose this aspect of the digital footprint to surface using a technology probe (described in more detail in Chapter 5). In the next section, I describe how existing tools fall short of meeting user needs for improved home network visibility.

2.2.4 Existing Network Tools

To date, the majority of home network tools are geared towards managing and configuring devices [43]. These tools allow users to access aspects of the digital footprint, but they have several shortcomings. For one, these tools do not usually provide an overall overview of the network layout. Another shortcoming is that in these tools the information is often presented in terms that are understandable to only to very technically knowledgeable household occupants, (e.g., command line tools like “ping” [48] or traffic analyzers like SNORT [88] or KISMET [55]) despite there being a range of skills in the home for networked related issues [86]. Moreover, most of the tools have not been designed for the home environment specifically, such as the existing commercial tools for wide-scale network administration HP OpenView [45], Etherape [29] and Ethereal [30]. These commercial tools are geared towards the workplace where there is a skilled network administrator. By contrast, in the home a dedicated administrator may not necessarily have technical training and often home networks contain fewer devices [17].

Devices on the home networks themselves may not have interfaces that are easily usable by the average consumer. For example, instead of having readable lights on the device itself, consumer routers usually have web interfaces. These interfaces may contain a wealth of information about the digital footprint presented in terms that cater to more technical users such as reporting the IP addresses and signal strength to all wireless clients on a network as well as graphs of bandwidth usage. Other tools for home network management seek to minimize user involvement further in the hopes of improving the technologies themselves, possibly obscuring the home's digital footprint. For example, in the NetPrints prototype developed by Microsoft Research India and collaborators [1], if a network problem occurs, the system consults a database of connected networks and searches for similarly configured networks to resolve the problem without human intervention (creating a network that fixes itself using shared knowledge). Collectively, although these tools try to address networking configuration problems, none of them specifically addresses the fact that the home network has fewer devices and that not everyone in the home is a network administrator. Further none of these tools focus on providing an overview of resources being used in the digital footprint, such as electricity, time or bandwidth. Surfacing this information on computing routines and resources in easy to understand terms to determine how this influences engagement with infrastructure may be the first step in developing a better way to visualize the digital footprint.

Exceptions to the above tools exist which do attempt to surface aspects of the home's digital footprint. One example is the tool Network Magic [62]. This tool allows people to view their home network layout and makes configurations and basic networking tasks such as adding a new device to the network easier. However, this tool is still designed to be used by a sole administrator. As such, the information presented is not necessarily usable by everybody in a household. Thus, it is difficult to assess using this tool alone how visibility of aspects of the digital footprint affects the non-technical users in the home. Moreover, Network Magic does not necessarily surface information around all network resources (although it does surface some information around routines such as when the network is used) such as network speed. Instead, Speed Meter Pro [89], a separate tool for accessing information about bandwidth speeds and identifying when Internet connections are slowing down exists. Similar to Network Magic, this tool does not necessary make aspects of the digital footprint accessible to everyone in the home other than the motivated network maintenance person. In an integrated view of the digital footprint, both aspects of this information could be made available to all householders, which is what I aimed to do as part of my research.

With respect to other applications for broadband speed measurement, tools from the FCC, M-Lab, Glasnost and popular sites such as speedtest.net exist [58,60,90,99].

Yet, it is unclear how many households are aware of, or regularly use these tools. Moreover, these tools only offer single point speed tests, without keeping a history of tests over time or an overview of performance from multiple machines in one household. More importantly, these sites are not tailored to the average consumer, providing tools that are difficult to install, and results that are not easy to interpret without a technical background. Therefore, although these sites are geared towards "enhancing Internet transparency", the question of how to surface this aspect of the digital footprint in a form factor that users desire or need to see, in a language they can readily understand, remains open.

Two tools that are exceptions to the above which are most closely related to my work with Kermit, are the Eden tool [104] and the Home Watcher system which I evaluated with six family households in the UK [14]. In Eden, a home network visualization tool, the research goals were to determine what aspects of networking infrastructure should be exposed to users as well how as well as how to implement the tool technically. Specifically, Eden focused on providing users with information on networking monitoring, security and quality of service in networking. Eden's focus was to provide a functional tool to help users with these aspects of networking. In contrast, with my own research, I wanted to design a research instrument to serve as proof-of-concept of the technical implementation of a networking system but more importantly, to help me uncover people's mental models of Internet speed and bandwidth as well as how users would like these concepts represented.

The Home Watcher tool, shown in Figure 1, helped households identify bandwidth hogs as a first step towards understanding what visual network tools that surface parts of the digital footprint might do for a home. For example, Home Watcher showed users all the computers in their homes as little colored circles on a central appliance display. In this central display, each computer's bandwidth usage was shown in real time and users could throttle any computer's Internet connection. With Home

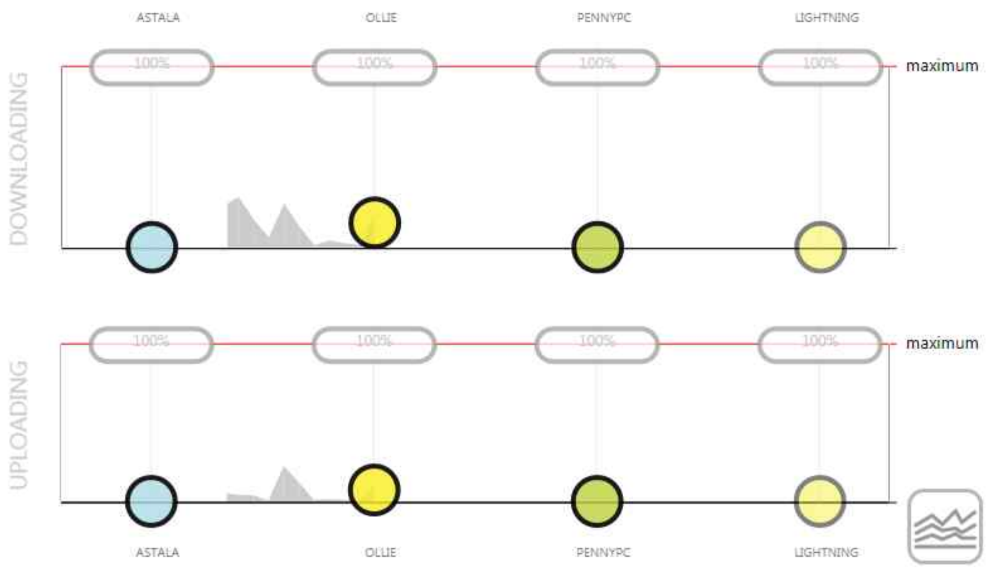


Figure 1: A screenshot from a participant's home of Home Watcher showing four machines connected on the home network. Each machine is represented by a colored circle with its hostname as an identifier. To throttle a device, a user drags the lozenge shaped button above that device.

Watcher's visualization of home machines' bandwidth usage, households were able to learn more about high bandwidth users. However, users wanted more control over how they were personally represented in a network visualization because the computers were only depicted as little colored circles and the computer descriptors used were the default computer hostnames.

My research builds directly upon the lessons learned from the Home Watcher study I conducted and focuses on making network speed and bandwidth information from the digital footprint visible to end-users. To create a usable prototype, I employed a user-centered design (UCD) approach [24] to design and implement a technology probe called Kermit. My goal with Kermit was to investigate how to surface the digital footprint. In designing Kermit, I have taken inspiration from other approaches such as ludic engagement [35] and reflective design [84]. Moreover, I was inspired by systems which take inputs from everyday life and make ambiguous mappings to provoke reflection and explanation of the resulting representations, e.g., the Home Health Horoscope [36] or the Tableau Machine [71]. These systems helped me realize that the network information could be visualized in a way that provided reflection and not necessarily just for troubleshooting purposes alone.

My own technology probe differs from these types of systems because I focus on making information about the digital footprint available for inspection to determine how this non-ambiguous mapping affects household occupants' engagement with infrastructure. I discuss how I chose which aspects of the digital footprint to surface based on my initial fieldwork as the first part in the UCD process in Chapters 3 and 4 as well as the technology probe design and evaluation in Chapter 5. In Kermit, I present an alternative network visualization to Home Watcher that allows personalization of icons [14] and I also provide the estimated Internet speed from the ISP. Kermit further differs from Home Watcher because I show all devices connected to the home network as opposed to computers alone; I allow users to prioritize any device's Internet traffic instead of just providing a throttle function; and Kermit is browser-based instead of a standalone appliance.

2.3 Chapter Summary

In this chapter, I first described how infrastructure suffers from visibility issues and how researchers have advocated for improved visibility to improve overall system intelligibility, accountability and usability. I also discussed how previous work has focused on surfacing information around breaks in infrastructure. I emphasized how my research is focused on surfacing information about the normal workings of infrastructure to determine how that affects users' engagement with infrastructure. Next, I described the emergence of home networks in the domestic space, my chosen case study of infrastructure and how these networks also suffer from visibility issues.

I then described how the visibility issues in home networks might be addressed through surfacing information on computing routines as well as associated resources through the digital footprint. Specifically, I outlined how previous home networking tools have not yet addressed the average home users' needs. I also discussed how users require information about broadband speed in particular and why this is a useful aspect of the digital footprint to surface. Finally, I described my user centered design approach to determine the effects of surfacing aspects of the digital footprint for home network users. In the next chapter, Chapter 3, I describe the first set of studies geared at understanding people's current conceptions of their digital footprint. I also discuss how these studies informed the design of Kermit, the technology probe I created to make aspects of the digital footprint visible for home network users.

CHAPTER III

MAKING CONNECTIONS: CONCEPTIONS OF THE HOME NETWORK AND THE DIGITAL FOOTPRINT

RQ1: *What visibility issues around the home network emerge from studies of households' engagement with networking infrastructure, and which of these are exacerbated by the lack of a visible digital footprint?*

My first set of studies answered this question by uncovering people's conceptions of their home networks and their digital footprint as well as how people engage with home networking infrastructure. I defined the home network as including any computing device such as a personal computer, router, modem as well as connections between these devices and audio/visual devices for entertainment such as televisions and set-top boxes. However, I chose to focus more on the computing infrastructure and activities related to these devices. Recall, the digital footprint of the home is the collection of all the information flowing through the home network, from and to the outside world and information on all the devices in the network. In this chapter, I describe the details of the two empirical studies conducted and at the end of the chapter, I summarize the resulting design implications for Kermit.

3.1 Study Methods

I conducted two empirical studies to investigate people's conception of their digital footprints, in Spring 2006 and in Fall 2007 (see [17, 86] for additional details). In each study, I conducted a home visit with my participating household. Prior to this home visit, I asked each household to complete a technology inventory detailing all the devices and technologies in their homes, whether these devices were personal or shared, and the types of network setup (wireless/wired/both). During each home visit, I asked each participant in the household to sketch out their home network, their ideal home network and their audio/visual networks. Each participant also explained their networking sketches in detail to clarify any points I did not understand. I was then given a home tour where the participants pointed out relevant home networking equipment in their homes. Finally I concluded the home visit with an interview about home networking general maintenance, setup, responsibilities and troubleshooting in the home.

During each home visit, I audio-taped the entire home visit, made field notes and took photographs of all interesting networking related equipment as pointed out by the participants. All the interviews were transcribed and coded for interesting phenomena in a grounded theory inspired approach. All codes were categorized and higher level themes were created and related to form an overall story. I led the coding and analysis process to arrive at the final results for both studies.

3.2 Participants

In the first study in Spring 2006, I recruited participants through word of mouth, mailing lists and from attending a parents-teacher association meeting at Grady High School in Midtown, Atlanta, GA. In total, 11 households participated in this study with 28 participants, including 5 teenagers. This study focused on generally uncovering issues around home networking infrastructure, conceptions of the digital footprint and roles in network maintenance. No compensation was offered for participation.

Most of the participants in this first study were families with children or married couples and had at least one household occupant with a technical background. Previous work has shown that studying earlier adopters yields rich data [40] so even those technically savvy participants provided rich data. Similarly, my sample set was particularly informative at a time when home networks were just becoming more

Table 2: Participant demographics for first study of home networks conducted in Spring 2006. Y indicates the presence of a type of connection and N indicates the opposite.

Household	Household Members Demographics	No of PCs	Wired	Wireless	DSL or Cable	Primary Care-taker AV	Primary Care-taker Com-puting
F1	Boyfriend [Networking Administrator] Girlfriend [Grad. student, technical field]	4	Y	Y	Cable	Both	Both
F2	Husband [Marketing/Sales], Wife [Grad student, technical field]	3	Y	Y	DSL	Husband	Both
F3	Husband [Builder], Wife [Usability Engineer] (Children not living at home)	2	Y	Y	DSL	Husband	Wife
F4	Husband [Prof., technical field], Wife [Homemaker], Son (8), Son (6), Daughter (3)	2	Y	N	DSL	Husband	Husband
F5	Boyfriend [Office Manager in firm], Girlfriend [Grad. student, non-technical field] (engaged)	3	Y	Y	DSL	Boyfriend	Both
F6	Husband [Network Engineer], Wife [Usability Engineer], Son (4), Son (1)	7	Y	Y	DSL	Husband	Husband
F7	Husband [Office worker in business], Wife [Homemaker], Daughter [User Interface Designer] (24)	4	Y	Y	Cable	Daughter	Daughter
F8	BrotherA [Grad. student, technical field], BrotherB [Undergrad. student, technical field], Roommate	5	Y	Y	Cable	BrotherA	BrotherA
F9	Husband [Prof., technical field], Wife [Instructor, technical field], Son (14), Daughter (11), Daughter (<11), Daughter (<11)	5	Y	Y	DSL	Husband	Husband
F10	Husband [Prof., technical field], Wife [Grad. student, technical field], Son (15), Son (9)	7	Y	Y	Cable	Husband	Husband
F11	Husband [Businessman], Wife [Homemaker], Son (>11), Daughter (<11)	5	Y	Y	Cable	Husband	Wife

Table 3: Participant demographics for the second study of home networks conducted in Fall 2007

Household	Household Members Demographics	No of PCs
S1	F, [Student] (26); F, [Student] (24)	2
S2	M, [Student] (22); M [Student] (23)	3
S3	F [Nutritionist] (28); M [Student] (28)	4
S4	M, [Student] (26); F [Student] (24); F[Student] (25)	4
S5	M [Student] (29); M [Student] (24); M [Student] (25); F [HR Coordinator] (25)	6
S6	M [Software Consultant] (27); M (Programmer), (26); M [Elec. Engineer] (24)	6
S7	M [Student] (26); M [Student] (28)	4
S8	F [Communication Director] (46); F [Lawyer] (49)	5
S9	M [Industrial Engineer] (24); F [Management] (25)	3
S10	M [Student] (28); F [Teacher] (28)	3
S11	M [Admin Coordinator] (41); M [Graphic Designer] (47)	3
S12	M [Software Programmer] (39); F [Mother] (39); M [Scholar] (8); M [Scholar] (5)	3
S13	M [Faculty] (36); F [Student] (38); F [Scholar] (7); F [Toddler] (3)	2
S14	F [Civil Engineer] (30); F [Public Health] (26); M [Restaurant Manager] (29)	3
S15	F [Recruiter] (49); F [Scholar] (16); M [Scholar] (13)	2

popular. Participant demographics for this study are summarized in Table 2.

In the second study in Fall 2007, I recruited using similar techniques to the first study, also in Atlanta, GA. However, in this study, I offered compensation to the participants, in the form of either a $20 Target gift card or a $5 Starbucks gift card for each member of the household. In this study, 15 households and 33 participants were involved in the research. In the second study, I also placed a deeper focus on equipment purchasing and equipment recycling practices. This second study confirmed much of the original results of the first study.

Participants in this study included roommates, couples (heterosexual and same-sex) and families with kids. Participant occupations varied from graduate students to engineers, lawyers, consultants as well as a full time mother. Most participants fell within the 20-30 years age bracket but the full range varied from 13-49. Participants' demographics for this study are summarized in Table 3. Note, I will refer to households in the first study by an F and then the household number, e.g., F1. I will refer to households in the second study with an S and then the household number, e.g., S2. Participants in the studies will be differentiated by a letter, e.g., F1a, S2b and so on to preserve anonymity.

3.3 Findings

In this section, I describe the findings that emerged from both of the studies I conducted. These findings informed the design of my probe to surface the digital footprint of the home— Kermit.

3.3.1 Stages of Home Networking

In general, my fieldwork revealed that home networking activities fall within three key phases, which consist of the following types of activities:

1. Setup—Activities and routines around installing the home network which may

require purchase of equipment, cables and designing the layout of devices and connections.

2. Maintenance—Activities and routines around adding or removing devices from the network and providing network access to guests and friends. These activities may also include backing up devices, periodically removing viruses and installing updates.

3. Troubleshooting—Activities and routines around determining how to fix problems with connectivity and equipment failures as well as determining why connections may be slowing down for instance.

Throughout the phases of home networking, invisibility of the digital footprint caused my participants to have less than optimal experiences with their networking infrastructure. Consequently this affected how they performed activities in all of the phases described above. I discuss this infrastructural "invisibility" next.

3.3.2 Invisibility Issues

Participants experienced issues related to the invisibility of their digital footprints because of both wireless and wired networking. I discuss these issues in turn.

3.3.2.1 Invisibility in Use: Wireless Networks

Invisibility of the digital footprint was evident in how people conceive of their home's physical site and their virtual or wireless networking sites. For example, participants in my studies often experienced problems with wireless networking. Often, they spoke of difficulties in determining how their WiFi network's boundary matched up to the physical property that the home was built on. They also could not easily ascertain at any time who was on the wireless network and whether it was secure or not. Instead, participants in my studies spoke of how it is easy to see who is on the physical property of a home but how this differs for one's virtual site or wireless network.

On the virtual site, at a glance, users cannot easily determine if there are intruders, if the network is secure or where the best wireless signals are in the home and why that may be. By contrast, one can easily have a fence or a wall around a property and can determine if someone is trespassing by tracking the home's boundaries. In surfacing the digital footprint of the home, giving users a sense of their virtual site and who is on it as well as where devices are located in the physical site could help them to better understand their networking activity. In Chapter 5, I discuss how participants reacted to information that made their virtual site more visible.

Regarding securing the virtual site or determining if the digital footprint is locked down, I found that people treated their own networks very differently from how they treated other people's networks. For one, they did not have issues with using other people's networks if their own networks broke down. However, they were concerned about the security of their own networks but visibility issues meant that often they did not realize if their networks were being intruded upon or not. One participant expressed her dismay at being able to see her neighbors' files:

> F1b: "If ours goes down, my computer will connect to the neighbor's automatically. And sometimes I will see printers and I am like "This isn't my printer". Or if you open up the file sharing stuff, then you'll see these files like Amy's files and Gene's files. And I am like "No that's the neighbors.""

Not only being able to see at a glance who is "on" the virtual site (or online) but having some control to more easily block access to intruders or grant access to authorized users such as friends may help users reconcile how their virtual site works.

Another consequence of wireless networks and technologies is that users find it difficult to determine how signals vary throughout the house and why. For instance, my participants created theories about why network signals were poor in parts of the home, in absence of real information (present in the digital footprint) to prove otherwise. For instance, one family felt that the kitchen appliances caused interference with the wireless network:

> F11b: "We figured out up high is the best place for the wireless. That's because with the kitchen right behind here, that's a problem in houses, it's the kitchen [that] interferes with the signal. With the refrigerator and the microwave—those folks generate radiation all the time."

Being able to see the signal strength of all devices in a central interface may help users discover how signal strength varies depending on the location of the device. By harvesting information from the digital footprint, one could show device signal strengths as well as an overview of all devices connected to a home network. Moreover, one could show users if these devices are known devices or unknown—potentially indicating trespassers. This type of visibility would make the information about the network as a whole more accessible and potentially help users more easily understand their virtual sites. In the Kermit probe, I chose to surface only information about who was online on the home network and why the Internet is slowing down. Next, I describe results around hiding wires for aesthetic reasons.

3.3.2.2 Wired and Aesthetic Invisibility

Invisibility in use was not confined to wireless networking alone. Rather, invisibility issues also surfaced with wired networking infrastructure because of participants' self-imposed network configurations for aesthetics. For instance, as home networks are built into the actual home's infrastructure, e.g., when Ethernet cables are laid within walls, often this increased invisibility and the inability to easily access these inner workings can cause problems. In one household, a participant could not determine why one of the two Ethernet ports in his office was not working. He suspected that a nail was put through the wire in the wall but could not fix the problem or prove

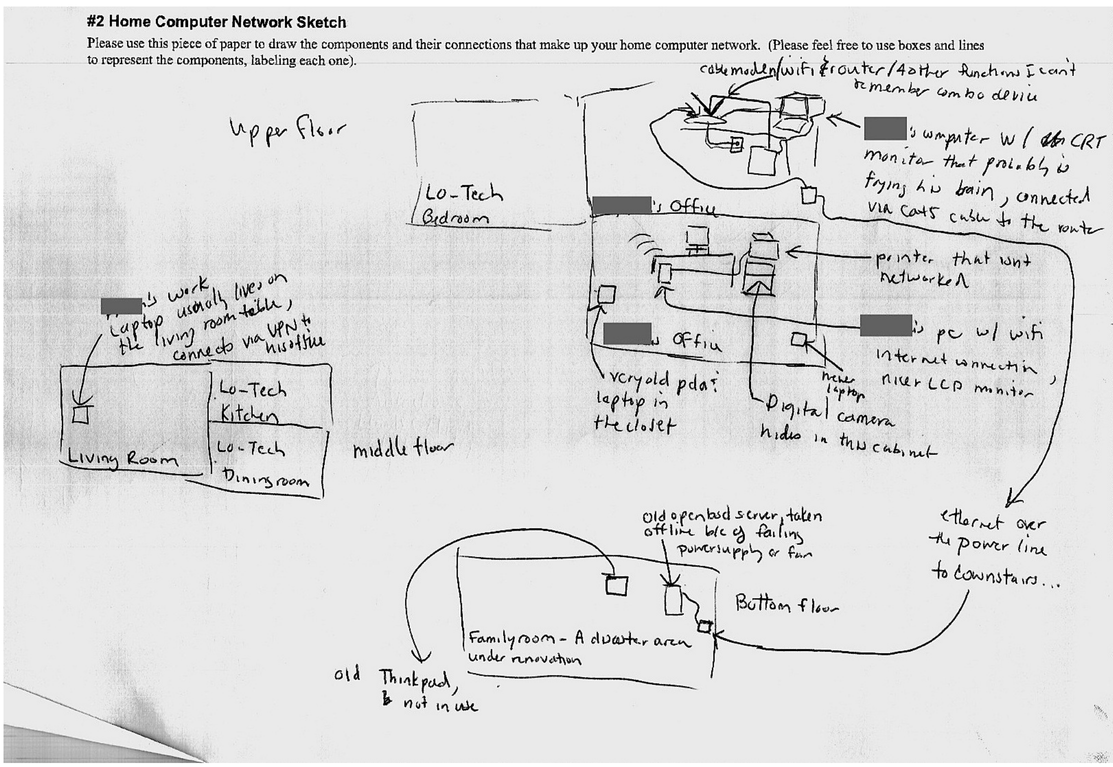


Figure 2: This sketch illustrates how the built environment is often represented and used to understand how the home networking infrastructure is situated within the home (F1).

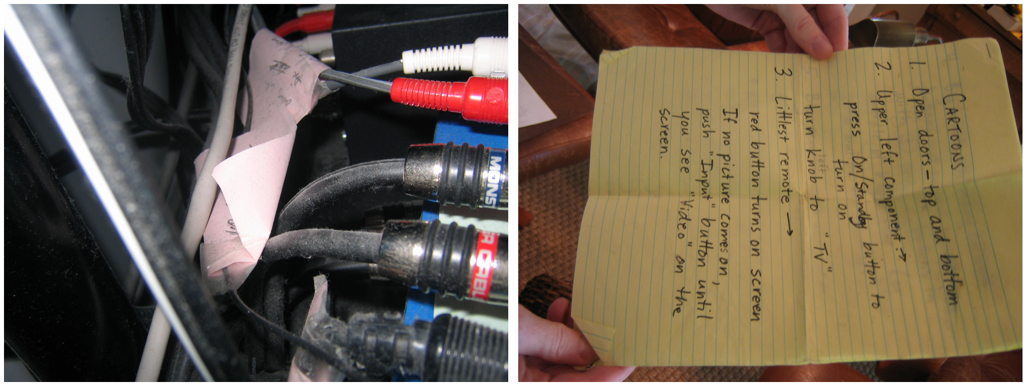
his theory without literally tearing up the walls. If he was able to view a network map (e.g., based on information from the digital footprint), he may have been able to more easily pinpoint if the problem was a general connectivity issue or just an issue with the wires to the office.

Oftentimes the reason for participants hiding away connecting cables and equipment was to maintain an aesthetically pleasing wireless house. I observed this self-induced invisibility of the home network manifest in remote controls placed in the cookie basket (F11), tightly stacked router and cable modem boxes tucked in the corner of a room (F2, F5), speaker systems and cables hidden away in indoor potted plants (F3, F4, F11) and equipment installed in cabinets with closeable doors to hide away devices when not in use. These findings made it clear that showing all devices on the network and the history of devices that have once been connected to the network may help households keep track of tucked away connections and equipment.

3.3.2.3 Invisibility and Distributed Devices

Home networking infrastructure also tended to be invisible to participants because of the large size of many American homes and because of the distributed nature of devices throughout many different rooms. This wide distribution of multiple devices made it very difficult for participants to get an overview of what was occurring on the network very easily unless they had invested in special administrative tools. In an extreme case, one participant's network extended between multiple buildings on one property. In this household, the owner had a guest house and a wireless network that her guest had installed:

> F3b: "He works from California...then he comes to in to CompanyX every so often. So he stays here in the room above the garage. And he's the one that set up the router so that he could have wireless access."



(a) Post-It Notes (b) Instructions

Figure 3: Post-it notes to remember how to connect devices together on the left and instructions for watching cartoons on the right.

My studies showed that networking equipment may be distributed throughout a home, hidden away for aesthetic purposes or built into the home itself. All these factors suggest making the home network setup and configuration more visible through revealing the digital footprint may help household occupants form better conceptions of their home networks composition.

3.3.2.4 Visual Reminders, Post-its, Instructions and Makeshift Representations

I noted that to deal with the invisibility of the digital footprint, many participants had developed strategies for managing the configuration information for multiple devices in the home network. I observed this phenomenon particularly in the first empirical study. Many of my participants created visual reminders for themselves such as Visio diagrams to represent their networks, or post-it notes to remember which wires plugged into which places. Several had even written out instructions for how to operate different equipment for kids and babysitters or guests as shown in Figure 3. These reminders tended to be static and scattered about the place at the points of interaction:

F6b: "'Cause literally when I did it, I actually put post-it notes on things.

> Like this is the output input here. And I would have post-it notes saying where it came from and what it was plugged into, in every wire."

The prevalence of these makeshift representations and reminders are testament to the difficulties inherent in maintaining, configuring, and managing a home network. In fact, my participants were so overwhelmed at times with the thoughts of connecting devices together that they simply did not even try. For instance, most of my participants did not even consider that networking their printers would be easy or that connecting their audio-visual network and computing networks together was within their capabilities.

Moreover, often when friends or family visited, my participants spoke of how they had trouble giving them access to their networks. Most often, they had misplaced or forgotten passwords for the network or in some cases, they had not set up the network themselves. Sometimes, participants desired the ability to remember old network configurations so they could roll back to a previous state when something went wrong as exclaimed by F4a:

> F4a: "I had totally forgotten that when I set up the router and stuff at first, there were a couple of passwords. Or there was an IP address you had to give it. And so, oh I know what happened. We changed the main account. We had to change a few other things and it affected [the network]. We had to go put that into the router. Yeah when you bring up the router screen, I don't know you bring the special webpage that's really the router. And I had a problem and it literally took me a couple of days. I'm like, 'Gee why isn't this working da da da.' And then finally I was just sitting there one day and it's like 'Oh I remember! I had to put in the password!'"

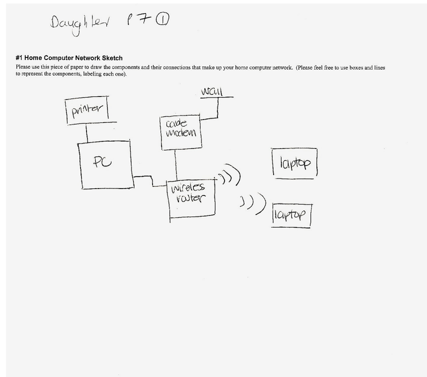
Surfacing the digital footprint and the layout of the network may dispel some of the mystery behind the home network. My results suggest that increasing the digital footprint's visibility can help users to understand how devices are connected and interact with one another. For instance, giving home occupants direct access to the digital footprint would enable retrieval of all device configuration data in one place. This information may decrease households' perception of how complex networking tasks are and help with the management of network information such as wireless passwords and device settings. Further, showing a history of devices which were once connected to the network or a history of configuration changes may help users with remembering the state of the evolving network.

3.3.3 Computing Routines

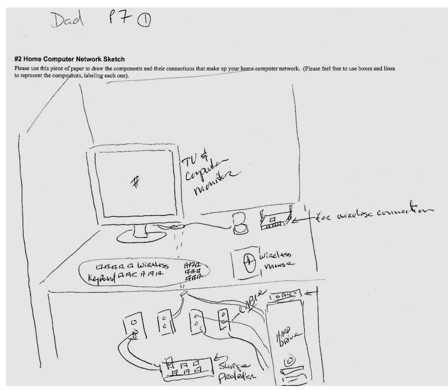
Along with invisibility issues because of the inaccessible nature of the digital footprint, I found that each home has computing routines and activities around the network. Moreover, I noted that each household member has a different role to play in these activities. I describe my findings around these themes in this section.

3.3.3.1 Roles in Computing Routines: Home Network Sketches

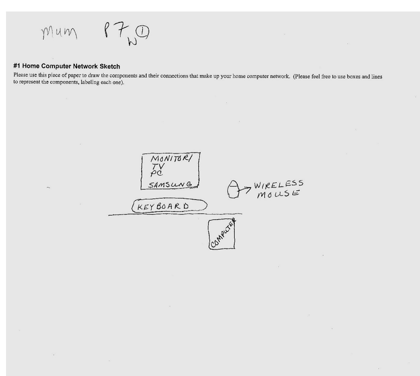
Home routines first started to become apparent upon inspection of the network sketches that participants filled out to show how their networks were laid out. Most evidently from the sketches, the roles that participants played in the three phases of home networking became clear from how they drew networking equipment and how they labeled this equipment. For example, I observed different sketched out views of the same network within households, e.g., see Figure 4, a kind of interpretative flexibility discussed by Bjiker [6]. In this household, the parents and adult daughter all view the network slightly differently based on their use of the network. The daughter used the network the most, her dad used it occasionally and her mom rarely used the network and was the least technically knowledgeable. Interestingly, unlike typical



(a) Daughter

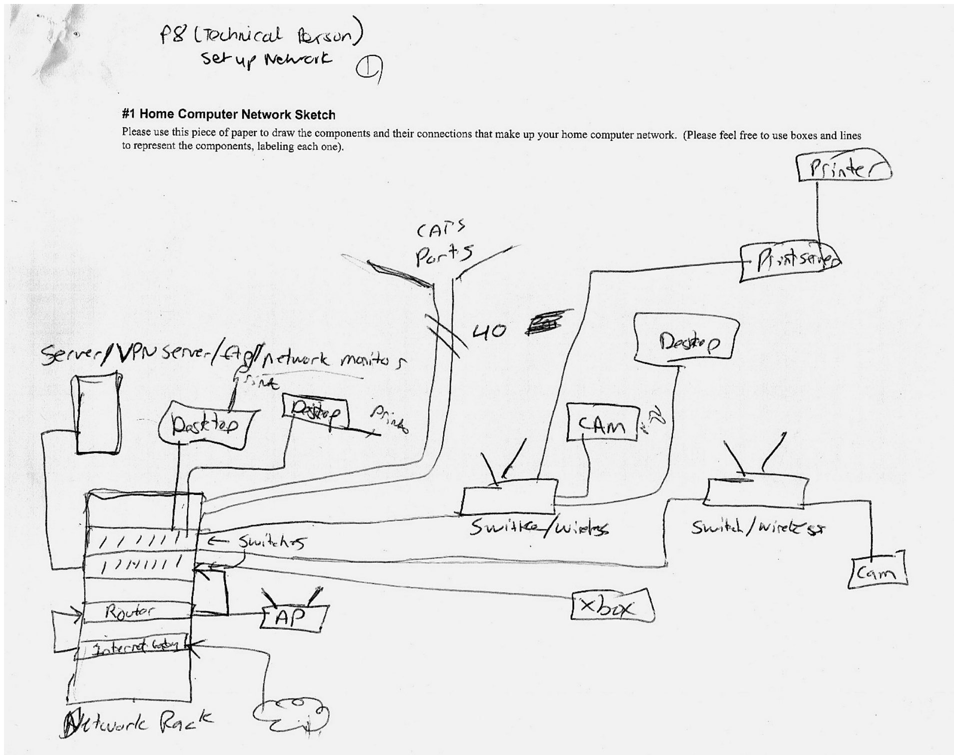


(b) Dad

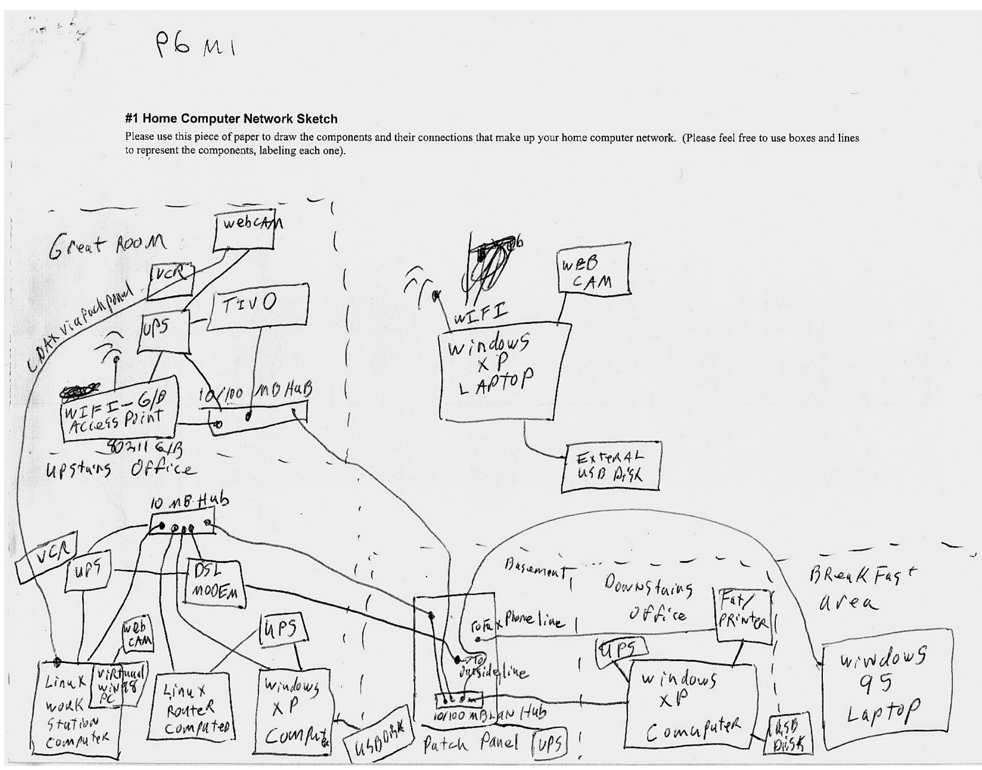


(c) Mom

Figure 4: This set of sketches shows the variability in drawings in the same family, F7. In this figure, the top drawing is the daughter's sketch, the middle is her dad's and bottom is her mom's sketch.



(a)



(b)

Figure 5: This set of sketches shows the more technically inclined drawings from F8 5(a) and F6 5(b).

network layout diagrams, pieces of equipment and furniture tend to be depicted in these informal sketches.

In a more thorough analysis of the sketches described in Shehan-Poole et al. [86], a colleague and I found that several roles related to the network were reflected in recurring themes in the sketch depictions. Specifically, we identified three types of roles defined by the types of drawings participants made and whether these drawings were primarily logical or spatial depictions of the network and if they contained references to technical terms or not. The three roles we identified are: consumers, assisters and gurus. *Consumers* are those who use the network but often ask others for help in troubleshooting it. *Assisters* are those who use the network, have some technical ability for problem solving and setup but are not the primary network maintainers. Finally, the *guru* tends to be the person most technically knowledgeable and serves as the go-to person for problem solving, setup, and additions or removals from the main network.

Generally, home occupants have different motivations for using the network and tend to draw the network based on how they use it and which roles they tend to assume in the three stages of home networking. Like the household occupants in Figure 4, my participants who did not have a formal technical background or who were consumers tended to draw the network as it appeared in real life, using depictions of furniture and literal layouts to structure their sketches. Those who were gurus and assisters tended to be more invested in network growth and maintenance. Additionally, these participants tended to have more carefully crafted and elaborate network diagrams.

In Figure 5, sketches that matched the guru role show how typically the more technically knowledgeable participants tended to draw their home networks using a logical and abstract layout similar to a traditional network diagram. Other visual elements that participants used included the depiction of equipment in relation the home's built environment, e.g., labeling where equipment was in the house or drawing rooms. Participant diagrams contained a host of information from labeling and associating devices with the people who owned them such as "Mom's computer" to including devices that were mobile in multiple places in sketches to indicate when there were many favored places to do computing in the home.

Participants also put in information about whether devices were working or not. Another finding of note was that participants only put in only as much detail in their sketches as related to their personal use of the network. For example, participants tended to draw only devices that they themselves used frequently, or that were in public places. Consumers and assisters in particular, often did not know about or forgot about devices used solely by other household members. From the analysis of the data including the sketches (described in Shehan-Poole et al. [86]), it also became apparent that home occupants also use fairly consistent depiction styles (logical/spatial/hybrid).

To surface the digital footprint, I determined that using the common elements depicted in sketches could appeal to household occupants. For instance, my results suggested that showing the network layout in a spatial sense (e.g., showing rooms where devices are located) could be one common denominator of information for all three types of network roles we identified. Another insight from this set of studies was that more logically depicted visualizations could appeal more to gurus and assisters. In both cases in line with the results of the sketching exercise, allowing users to associate devices with people that own or use those devices or to add their own custom labels for equipment and rooms would be a necessary feature in a system to make the digital footprint more accessible to consumers, assisters and gurus.

In both the first and second studies, I also noted that users engaged in a 'Do-It-Yourself' building out of the home network tended to be gurus. These more technical participants often carefully planned out their networks and allowed for space for expansion in their designs. An example of expansion included envisioning adding new devices in the future or leaving spare connections for guests. They also took care to choose which cables were used for network connections (for wired networks), where they placed these cables as well as where electrical outlets were placed. Participants were oftentimes limited in how they could build their networks into their homes because they were constrained by other home infrastructure. For instance, in some cases participants had to ensure there were extra electrical outlets near where they wished to place future networking equipment. (Others [101] have already commented on how laptops are often not as portable as one would assume because they need to be plugged in, so use is somewhat constrained by where the electric outlets are in the home.)

Generally those participants engaged in this type of digital DIY, had formal technical training, such as such as a degree in computer science, speaking to the complexity of such undertakings. My field studies suggested that visualizing the computing routines in accessible terms could give others in the house a sense of the network layout and evolution over time. Simultaneously, improved visibility may help gurus in their quest to manage their ever-changing networks.

3.3.3.2 Roles and Self-Efficacy with Technology in Computing Routines

Another aspect of computing routines that became apparent in my fieldwork was that the roles participants assumed around the network, as well as their own identity issues, affected how much they engaged in computing routines around network setup, maintenance and troubleshooting. For instance, from the interviews, I noticed there was definitely a gendered difference in terms of who was responsible for maintenance of various parts of the home network. Most of the gurus for the audio-visual networks tended to be male whereas for computing equipment, the most technically knowledgeable individual tended to troubleshoot and maintain the network. I noted this similar pattern in my second study as well. In same-sex couples, one person tended to fulfill the role for both audio-visual and computing networks. More interestingly, not being able to deal with computing or audio-visual problems sometimes made the less technical participants feel inadequate. For instance, in the second study, one participant said:

> S8a: "I mean like I feel like I'm so far behind, I couldn't just catch up with scary technology."

This apparent lack of computer self-efficacy for engaging with the home network was more evident amongst network consumers and assisters. Yet even gurus sometimes felt unable to cope with problems—an identity issue discussed further in Shehan-Poole et al. [87]. In fact, all three user types typically employed a tried and tested solution for solving networking problems, the so-called mantra of "reboot, reset", crossing fingers and hoping it all works. For instance in my second study, in S9 and S4 respectively, participants exclaimed:

> S9a: "Well, I just learn to unplug them and replug them back in so they would restart, that's all."

and

> S4b: "Frequently I just unplug like... sometimes I can't get my computer on. So I just unplug it and plug it and again."
> S4a: "Sometimes the router can kind of just stop working. So we just, you know, power cycle the devices."

My results suggest that there are clearly different roles for users in terms of maintaining the network, and each of these user types views the network in abstract, spatial or logical terms. Therefore, for Kermit I realized that the digital footprint can be made visible in different ways to appeal to various household members. My findings also suggested that if digital footprint is made to be accessible or digestible by all the household occupants, this information may affect the perception of technical self-efficacy that different network users feel. For example, consumers may understand more about what is going on with the home network, if the information is presented in terms that they can relate to easily.

3.3.3.3 Computing Routines and Parenting

Others have commented on how families deal with technologies with respect to parenting. For example, a UK study by Livingstone and Morill [56] briefly mention how parents regulate the Internet either unobtrusively (e.g., by placing computers in public places), through restrictive practices (e.g., limiting the time spent online) or through benign neglect, i.e., not actively monitoring Internet use at all. In further work, Livingstone and Helsper conducted a survey on parental mediation of Internet use to determine how well teens are protected from online content that is inappropriate [57]. Similarly, Rode studied practices around keeping children safe with technology use in the home [79]. My work expands on these studies by examining how a networked connection affects parenting practices.

In my study, the home network complicated the practices of giving children access to the Internet and monitoring their use of their network. For example, participants who were parents talked about how they do not want always-on wireless network access or Ethernet access everywhere in the home. One mother actually removed her son's wireless card from his laptop to prevent him from accessing the Internet from his room so she could more closely monitor his use of the network.

> F11b: "So no Internet in the bedroom. That's our big barrier, yeah. No Internet in kids' rooms. But he [son] can use it here [kitchen] in public."

Knowing who is connected to the network at any one time may provide parents visibility into how their children are using the network, although this arguably may be considered a privacy violation. My findings also suggested that having a mechanism to control childrens' network usage or reflect on whether and how often children are on the network may affect how parents create policies around the network use. Similarly, I predicted that children may be more or less inclined to use the network dependent on how accountable a visualization is in terms of making it known "what everyone knows" about how the network is being used. A recent paper by Yardi and Bruckman [105] that focused exclusively on techno-parenting for teens also supports the suggestion that visualizations providing parents with an awareness of their children's activities online might facilitate parental duties.

3.3.3.4 Computing Routines and Resources: Time, Electricity and Bandwidth

Routines around home networking become apparent from my fieldwork. I also noticed that resource usage in terms of the time spent on computing routines, and the power behind the digital footprint in terms of bandwidth and electricity were largely invisible to users. With respect to time as a resource, participants, particularly gurus and assisters, spoke about carving out or making time for network related tasks, such as backup, adding a new device to the network or troubleshooting problematic equipment. Time also emerged as a theme in the network sketches in representations of how the network evolves on a day to day basis. Aside from participants representing mobile devices in multiple places in the home (showing how devices move around the home), they also put in equipment that was unused and/or broken or that had been taken out of the network temporarily for repairs in their sketches. For example, in the first study, as seen in Figure 6, one user drew a desktop that was sent for repairs. In the second home networking study, I noted similar phenomena, for example, household S11 showed an unused laptop in their drawings. A corollary to this is that often as I went on the home tour, or as participants compared their sketches to other

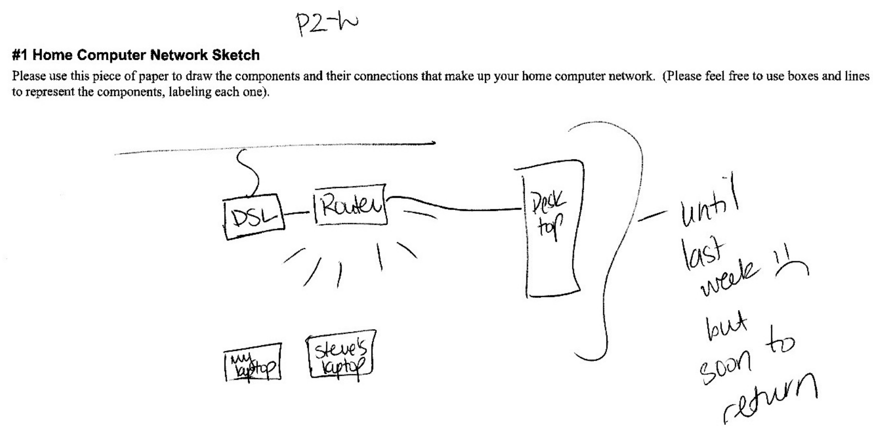


Figure 6: This sketch shows how often broken/unused equipment is still represented in drawings (F2).

household members' sketches during the interviews, they realized they had forgotten key equipment in their sketches. Usually, these slips of memory occurred because a device was out of use or the sketcher was not the main user of the device in question.

My findings from these studies suggested that it may be helpful to incorporate the notion of time into a representation of the digital footprint. In this way, one could depict changes in the network or configuration to help users track how the network evolves over time. Further, because computing routines and resources fluctuate over time, helping users better track a history of use will be beneficial for returning the network to a previously working state, remembering old configuration details and understanding new additions.

My participants also noted that visibility of other resources that computing routines require was poor. For instance, they complained that there was no information around how much bandwidth occupants are using or even how much electricity end-user devices utilize. Often, the more technically minded participants were interested in bandwidth and identifying who on the network was using the most bandwidth or creating bottlenecks:

> F8a: "If there's low throughput or if my upload or download is really bad, I look at the network monitor to see who's hogging the bandwidth."

Today, as more ISPs implement bandwidth caps [19], knowing who is contributing to the cap in the house or even where the home sits in terms of the cap at a glance would be an essential part of the digital footprint to surface. Other participants, particularly in the second study, also noted that they did not consciously know how much power the computers were using but that this would be of interest to them. This is evidenced by the following quote:

> S7a: "Yeah 'cause you would imagine that you would be surprised. Possibly something that you think is taking a lot of energy is actually not."

I investigated the use of resources, particularly power usage in a follow up field study which I describe in detail in Chapter 4.

3.4 Chapter Summary

In this chapter, I described my empirical results which motivated the need for visualizing aspects of the digital footprint to improve the visibility of the home network. My results suggested that doing so would provide household occupants with insights into their computing routines and resources that they devote to these computing routines. Specifically I asked:

What visibility issues around the home network emerge from studies of households' engagement with networking infrastructure and which of these are exacerbated by the lack of a visible digital footprint?

Collectively, my two empirical studies showed that visibility issues do exist for home networks. Moreover, I found that each home has computing routines or activities related to network setup, maintenance and troubleshooting. First, because the digital footprint is largely inaccessible to household occupants, there are visibility issues around wireless technologies, wired technologies and in some cases, because users are more concerned about hiding devices away for aesthetic reasons. Second, because of the distributed nature of devices on the home network and the information needed to manage those devices being contained in make-shift representations, home occupants could benefit from improved visibility of the digital footprint. Third, there are clear routines around networking such as the roles users assume and play in managing the network.

Furthermore, users experience different levels of technical self-efficacy which may prevent them from attempting to engage in certain networking routines. My findings also showed that users create policies and computing routines around parenting children. Finally, my studies demonstrated that occupants are often interested in, but unaware of resources that computing routines require. Many of these visibility issues could be exacerbated by the lack of an obvious digital footprint.

Overall, my results implied that there is a need for us to surface the digital footprint. Doing so, could improve visibility of the computing routines and resources that the home network requires. My studies suggest that this kind of visibility may alter how users engage with the home network and consequently alter these routines or even perceptions of technical self-efficacy around the network—with technical efficacy being the perception of competence that people have with respect to technologies.

I used these results to inform the design of a probe called Kermit to investigate the effects of increased visibility on users' engagement with the home network. Based on the empirical data, I designed the Kermit probe to appeal to all three types of roles I identified. Therefore, I opted to make the information I presented as simple as possible. I also chose to focus the probe by showing network users at a glance who is online on the wired/wireless network, and when they are online. Further, I provided a feature where occupants could label devices as they desired as a mechanism to associate devices with the household members that use or own these machines. I speculated that this view would better allow occupants to obtain distributed device and configuration information at a glance.

With Kermit, I also wanted to make parts of the digital footprint that show what types of activities are going on from network use more visible. In particular, because of my studies, I chose to focus on bandwidth traffic information. My assumption was that such information would be key for creating policies in the home around network usage (e.g., for parents).

I wanted Kermit to be accessible to everyone on the network in simple terms. Therefore, I designed the probe so that anyone could easily access it using existing interfaces in the house, such as personal computers. Based on the findings above, I identified the following aspects of the digital footprint to make more visible (Note: further details are provided in Chapter 5):

- "Who's online": In this screen, I wanted to make the virtual site (wired and wireless) more visible to users in the home. I designed this view to allow users to customize a device representation of their network. For each device on the network, users are able to label the devices with names of their choosing, e.g., "Mom's laptop" or associate a different picture with each device, e.g., show a picture of Mom to represent her laptop on the network. In this view, users are also be able to access device configuration information about all the networked devices to aggregate this often distributed information (e.g., for users who usually create make-shift representations to keep track of this information).

- “Who’s hogging the bandwidth”: I designed this screen to show users the resources that computing routines require such as how much bandwidth different devices on the network are consuming in real time and historically.

In the next chapter, I will describe the more in-depth empirical study I conducted of computing routines particularly around the resources they require. My focus in this next study was on users knowledge of network resources such as time and power usage as well as the corresponding implications for surfacing the digital footprint. The full Kermit probe design, implementation and evaluation details are discussed further in Chapter 5.

CHAPTER IV

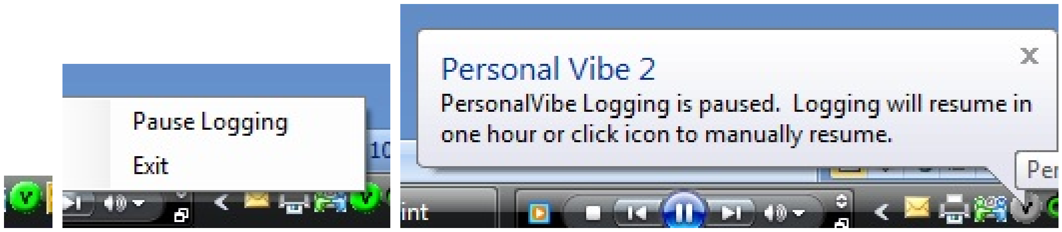
COMPUTING ROUTINES AND RESOURCES BEHIND THE DIGITAL FOOTPRINT

RQ2: *How do households perceive their computing routines and the resources they use for engagement with home networking infrastructure, and how much of this is visible through the digital footprint?*

To answer this question, I conducted a scoped in-depth study of household routines around resources that the home network requires. I focused on power consumption because of the interdependence of the home network on the electricity infrastructure in the home. Specifically, I focused on investigating how home occupants engage in routines to manage power usage around the main user endpoints of the home network: personal computers. In this study, I also used a limited technology probe to determine what users would do when presented with information about how they use their computers, a first step at examining computing routines as a whole. In this chapter, I describe the fieldwork in more depth and at the end of the chapter, I draw out the implications for the design of Kermit.

4.1 Study Method

I conducted this study in Summer 2008 using a multi-method approach [15], as part of an internship at Microsoft Research in Redmond (MSR) in collaboration with A.J. Brush, Brian Meyers and Paul Johns. I used software developed at MSR called PersonalVibe to quantitatively log all computer usage in participating households. This tool enabled me to log the activity of each user logged into a computer including applications used, duration of activity and whether the user was active or idle. To



(a) (b) Pausing the logging (c) Paused logging

Figure 7: The PersonalVibe logging icon and pausing action. 7(a) shows the green icon denoting that PersonalVibe is running. In 7(b), right clicking on the icon, shows two options to exit the program or pause logging. 7(c) shows the message that is displayed if logging is paused.

complement the activity information I collected with PersonalVibe, I created a Windows Service in C# called PowerLogger. With PowerLogger, I logged all computer power related events such as hibernate, standby, shut down and powering on. My aim was to determine what power state each computer is put into when computers are idle.

I also wrote scripts to collect the power settings on participants' machines and an installation program to help participants install all the software. For the logging software, I did not collect any information about URLs, window titles and other information identifying documents being created, videos watched or web sites visited. This privacy-preserving mechanism was taken to encourage people to participate in the study without fear of having personal browsing habits or sensitive information such as banking details being logged. Furthermore, the PersonalVibe software could be paused at any time if participants wanted to prevent information being logged as shown in Figure 7.

To collect the SQL database from each machine and text file generated by PowerLogger, I used a data extraction utility written by other programmers at MSR. For a more in-depth understanding of networking issues, I conducted in-home interviews and administered surveys, with a focus on computer power management. All of the interviews were audio-taped and later transcribed and coded using affinity diagramming. The surveys were analyzed using SPSS. I wrote initial analysis scripts in SQL and a program in C# to analyze the database logs. My analysis was complemented by colleagues at MSR who added to the programs and scripts to expand the final analysis. In total, I collected the following data:

- Logs of laptop and desktop use (all applications used, power events, duration of use) for all computers in participating households using PersonalVibe and the PowerLogger service
- A snapshot of the power settings on the devices at the start of the study. I collected this information with a script which ran with the installation application
- Pre- and post-study interviews and surveys on power management and computer use in general in the home
- Demographic surveys and a floor-plan sketch of where devices were located in the home
- Reactions to a motion-sensor application I developed to turn a monitor on and off to determine how people would react to automatic resource management for power savings

4.2 Participants

In total, 20 households with 83 occupants participated in the study. I recruited 10 families internal to MSR and ten outside of MSR and compensated households with software or lunch coupons. A high-level summary of participant demographics is shown in Table 4. I included families external to MSR to balance out any effects of a potentially more technically savvy sample drawn from MSR alone. For the ten families inside MSR, I delivered installation kits containing a pre-prepared USB

Table 4: Participant demographics for the study conducted in Summer 2008.

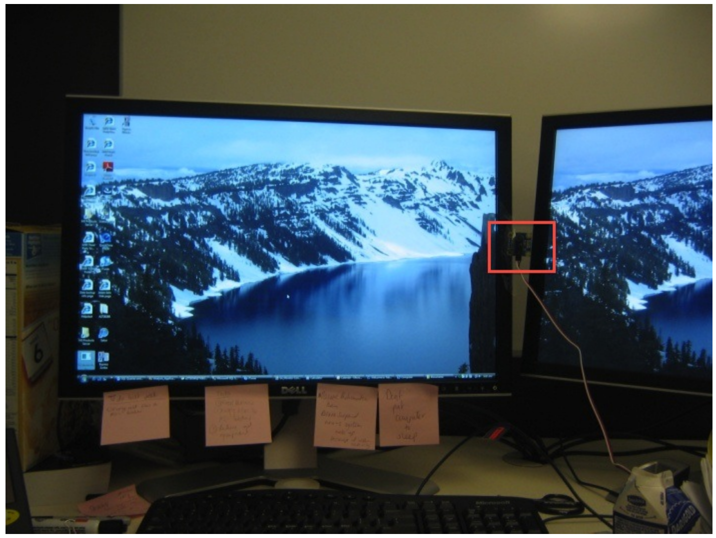
Household	# Adults	# Kids	# PCs	# Shared Devices
1	2	3	4	2
2	2	1	3	0
3	2	1	3	1
4	3	2	3	1
5	2	2	2	1
6	3	2	3	2
7	2	2	2	2
8	3	4	2	2
9	2	2	4	2
10	3	2	3	2
11	2	2	3	3
12	2	1	2	1
13	2	1	3	2
14	2	2	1	0
15	2	3	7	2
16	2	2	3	1
17	2	2	2	1
18	2	3	4	3
19	2	2	4	3
20	2	2	2	1

drive complete with an installer and instructions for step-by-step installation of all the components of the logging software, a floor plan sketch, a pre-study survey and demographic survey. I then collected the kits from these households and provided them data collection kits at a minimum period of two weeks from the first installation visit. In the data collection kit, there was a post-study survey, instructions for data collection and another USB key with the collection and data viewing application on it. I then collected these kits from the participants.

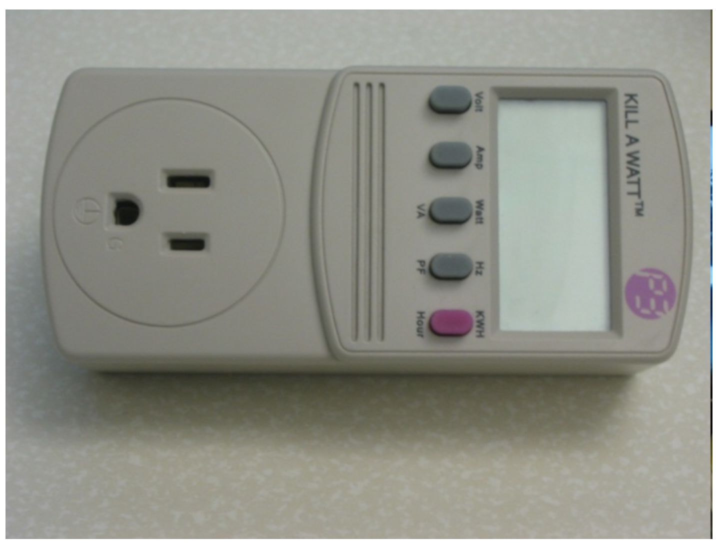
For the external households, I conducted two home visits, an installation visit and a data collection visit at a minimum of two weeks after the first installation. During the home visits I installed our software (or removed it along with the data), conducted in-depth interviews and collected all surveys and floor plan sketches, with the aid of a colleague. I also showed participants a motion sensor application to switch a monitor on and off, that I had developed using Phidgets [69]. My aim with the sensor application was to gather participant reactions to this type of application for automatic network resource management. Additionally, I showed participants a Kill-A-Watt—a device to measure the electricity consumption of appliances to gather feedback about measuring device electricity consumption. I audio-taped all the interviews and I took photos of network related equipment where I could. To supplement the data collected from my participants, I ran the motion sensor monitor application on my desktop for several weeks to see how it worked over time with my comings and goings from the office setting. This in-house testing allowed me to gauge how automatic home network resource management for power might work.

4.3 An Obscured Digital Footprint: Invisibility of Routines and Resources

From this in-depth study, three main themes arose which affected how I designed the Kermit probe. The first theme is around the invisibility of resources used by computing routines. The second theme is around the invisibility of computing routines



(a)



(b)

Figure 8: 8(a) shows the motion sensor application on my work desktop. 8(b) shows the Kill-A-Watt device which we took with to each participant's home to measure participant computers' power consumption.

themselves. The final theme that emerged is that increased visibility of the digital footprint even in lightweight terms can alter how users view the home network, their routines and the resources that the network uses. I elaborate on these themes below. More details of the other study findings are presented in Chetty et al. [15].

4.3.1 Computing Routines around Resources: Power Settings, Technical Knowledge and Agency

From this study, I became aware that there are clear computing routines around resource management. Similar to previous work [75, 101], my participants cited time and inconvenience as the most common reasons for leaving computers in the home network on. Participants also told me that they had other reasons for leaving home networking equipment, such as personal computers, on. In some cases, these devices acted as servers or would not function if not at least in standby mode—as is the case with TiVo's. My findings also revealed other insights above those covered by previous work.

Much like dealing with the complexity of the home network as a whole, often my participants did not know how to optimize the individual network end-points. Mostly this "inefficiency" occurred because they were not aware of their options for power management. For instance, participants did not necessarily know that different power states existed for desktops and laptops. Moreover, usually one household member was left with the job of managing the computers, i.e., usually the guru whether unwillingly appointed this job or not. These household members tasks included the responsibility to change the power settings or help others to improve power management practices.

Many participants also complained that certain power features such as hibernate or suspend did not work well and they were reluctant to use them. In other words, many of my participants appeared to lack a sense of technical self-efficacy with respect to resource management routines in the home network. Again, like the roles I identified in Chapter 3, one household member assumed the responsibility for turning off all shared devices. This turning off practice occurred at night or at other times when the household would be away, e.g., on vacation. For personal devices, usually the owner of the device took responsibility for turning their device off.

Correlating the above information gathered from the qualitative data with the logs, I found that users did not alter their power settings much from the default profiles that shipped with Windows XP or Windows Vista. In fact, even if participants tweaked power profiles, oftentimes they were made less power-efficient. For an example, many participants increased the timeouts for machines to enter low power modes or disabled low power modes altogether. In my interviews, participants complained about the inefficiencies and frustrations associated with the power settings on their machines. One common example provided was that the screensaver often started up when users were watching a video. These bad experiences most commonly resulted in users disabling these low power settings. Most never re-enabled them. Related to this complaint, many participants did not necessarily see the benefits of better power management over the convenience of having an computing device on to take advantage of an always-on connection.

Overall, my results from this field study confirmed that home occupants have differing senses of self-efficacy around resource management in home computing routines. Different household members also assumed different roles based on how they shared the device in question or in some cases based on ownership of the device. These results again suggested that showing the digital footprint in terms that are accessible to all household members could increase perceived levels of self-efficacy with technology, particularly for consumers and assisters. For Kermit, this meant that my design had to be simple enough to be comprehensible by anyone in the home.

4.3.2 Invisibility of Resources Used by Computing Routines

Along with participants having clear routines around resource management in the home network, I also found that there was a lack of general visibility around the resources used by the household for computing routines, with power use being no exception. In fact, the electricity consumed by network devices was generally not visible, especially for desktops due to the relative invisibility of the digital footprint:

> H81: "Like I said if you look at a laptop, everybody is always looking at the battery power on a laptop. But on a desktop there's absolutely no concern with that at all. It's not even part of the picture, yet it's an integral part of a laptop's picture. So it's kind of odd that there's two separate norms with desktop and laptop when it comes to energy use."

In this study, along with the invisibility of power usage I noted, I also determined how much time participants were using for network related activities or their computing routines. To calculate this aspect of home networking, I worked out how often participants left their devices on without actively using them (on) versus how often their devices were on and actively being used (active). My results showed that participants were only actively using their computers for about one quarter of the time that they were left on, as Figure 9 demonstrates. The top activity graph shows a computer that was mostly on when it was being used. In the bottom activity graph, a computer that was mostly on but only used for a small percentage of that time is shown. Clearly, different devices are used with various types of on/active ratios depending on whether they are shared, who is using them and where they are located. Shared devices, for example, tend to be left on so that multiple people can quickly use the machine when its free without having to turn it on and wait for it to boot up. I found that my participants were either heavy or light users, and that they had varying tolerance for waiting for machines to boot up. My data also suggested that

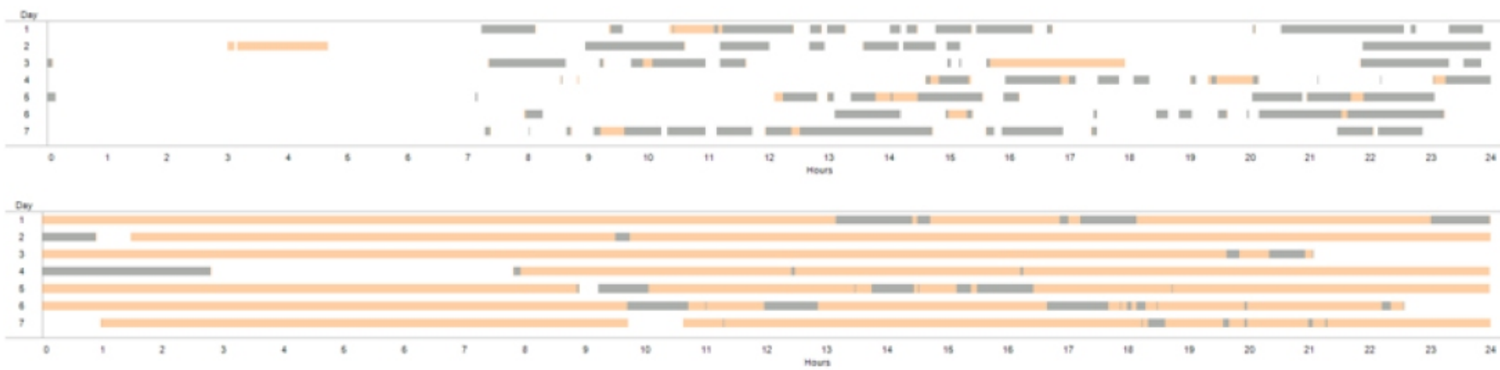


Figure 9: Example activity graph for two computers for one week. The rows indicate logged days, orange is 'on time' and gray is 'active time'. The bars show the duration of the activity during the day, with midnight starting on the left side. The top computer is typically only on when being used. The bottom computer is left on most of the time and rarely active.

if devices were located in a public setting, they were most likely to be left on most of the time.

My data also revealed that in my study sample, even if the on/active ratio was near zero, i.e., if people only had their devices on when they were using them, that the savings of power and money would not be significant. Essentially, I calculated savings to be in the order of $5 per year per device. Aggregate savings would be much larger as some participants noted:

> H62: "Everybody needs to realize too that if you have this household times 50 million others, it is a significant energy savings. If things are optimized, so it may not be a monetary incentive per household, but collectively it can save a lot of energy. People need to realize that they may not be saving much [of their] own money but they're in a society. And they can collectively do things to improve it."

Even with the small savings, what was more apparent from this study was that there is a general lack of awareness of resources that the home network is using. My results suggest that helping users understand more about how much power their home network is using, whilst not creating huge savings, may improve energy awareness overall. Further, as other work has shown different home occupants may be motivated to conserve or engage in resource management differently, e.g., usually the bill-payer is very motivated to be energy efficient as are "green" household members [18]. Given that power-usage information is part of the digital footprint, it could also be made more visible to home occupants. I left this aspect of visibility for future work and did not implement showing power usage of computing devices in my Kermit probe.

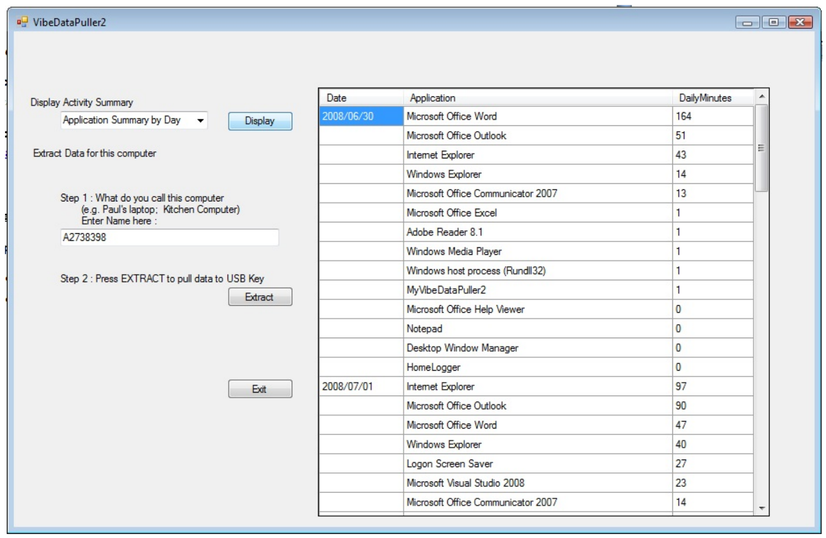
4.3.2.1 Personal and Family Reflection on Computing Routines

My participants were also not aware of how much time and energy they were spending on their home network. For example, most told me they were not aware of how often they were using their computers. Many did not even have a general sense of what they were doing on their computers (e.g., work or play) or how often they used certain applications on the network. Most surprisingly, when I showed participants a simple log of their activity on each device (e.g., date of use, duration of use and application name, as seen in Figure 10), they consciously reflected on their computing routines and household policies as well as day to day life.

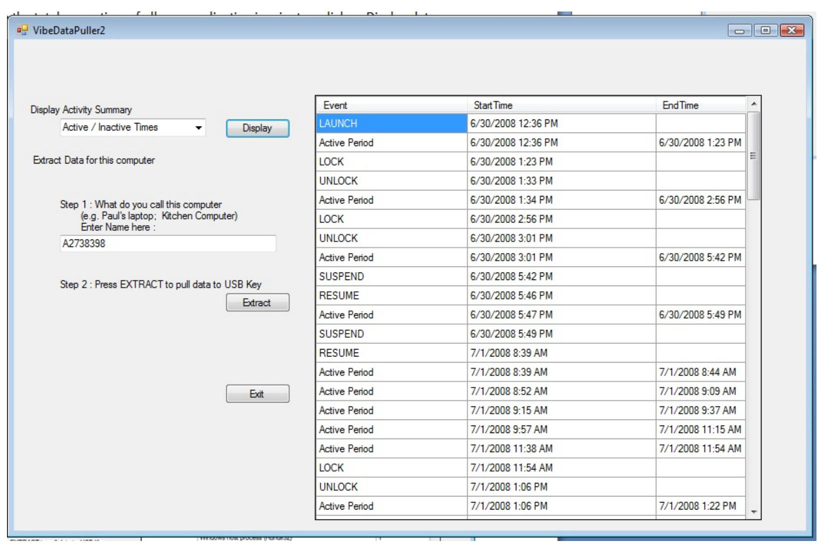
For example, participants viewing the logs of computer use often remarked how they did not realize they were playing so many games. In other cases, participants felt that the logs were reconfirming what they had self-assessed themselves to be doing, e.g., "I am working a lot". In some cases, family reflection raised interesting privacy concerns about who sees the logged data. For instance, in one case, when I was collecting the data of a young boy while his mom was there, she noticed in his logs that there was one evening where he was recorded as being online past 11 p.m.. She remarked on this and asked him what he was doing as she thought he had gone to bed. He confessed to be watching a DVD late at night:

> H9: Mom: "11:07pm huh?"
>
> Dad: "Busted!"
>
> Me: "Oh that was on the 20th?"
>
> Son: "Oh yeah. That was like a week ago and I was…"
>
> Mom: "Gotcha! Yeah, you were looking at videos on YouTube, weren't you?"
>
> Son: "I was looking at my DVD!"

From this interaction and reaction from participants, it became evident that making the digital footprint more visible could provoke reflection on computing routines and associated resources. Moreover, my findings showed that this information could alter how participants engage with the home network. Furthermore, I noted that in



(a)



(b)

Figure 10: Logging reflection interfaces showing times of application use (day and time of day), duration of use (in minutes) and application name in 10(a) and human-computer interactions in 10(b).

surfacing this information, privacy becomes a concern. In particular for the design of the Kermit probe, I had to ensure that all participants understood exactly what was being tracked and displayed to others in the household.

4.4 Chapter Summary

In this chapter, my empirical results showed that surfacing information from the digital footprint about time and resources used for home networking may affect how people engage with the network. Specifically I asked:

How do households perceive their computing routines and the resources they use for engagement with home networking infrastructure and how much of this is visible through the digital footprint?

The empirical study I conducted suggests that people do have computing routines and roles that are particularly tied to resource usage. Further much of resource usage and those associated computing routines are invisible to home occupants because the digital footprint is largely inaccessible. Finally, when parts of the digital footprint that show computing routines are made visible, home occupants are prompted to consciously reflect on their routines, the resources they use and the policies they have created around the network (e.g., such as when children should be accessing the network).

Based on these empirical findings, I designed Kermit to make network resource usage more visible to participants, with a focus on bandwidth usage. My aim was to provoke household reflection and alter users' engagement with the home network. To achieve this goal, I added details to the Kermit screens to show participants who was using up the most bandwidth on the network, and historical charts so that participants could see their bandwidth usage over time. I also gave participants the option to control their network by limiting or prioritizing certain computers' bandwidth, to provoke deeper reflection on home network routines, resources, and policies. More details are provided in Chapter 5. Next, I outline the design, requirements and implementation details for the Kermit probe, and I describe how I evaluated this probe in a month long field trial.

CHAPTER V

SURFACING THE HOME'S DIGITAL FOOTPRINT WITH KERMIT

RQ3: *How will surfacing invisible aspects of the digital footprint cause changes in households' engagement with home networking infrastructure? Specifically, will the following user engagements change as a result of interactions with Kermit, a technology probe for surfacing aspects of the digital footprint based on findings from RQ1 and RQ2:*

- *RQ3.1: Change users sense of self-efficacy with respect to the home network*
- *RQ3.2: Change computing routines and the awareness of resources users use e.g., Through increased problem solving, increased awareness of bandwidth, time spent on computing routines or via other emergent behaviors*

Based on the implications for design discussed in Chapters 3 and 4 and to answer the final research question, I designed, implemented, and evaluated a technology probe called Kermit. Kermit surfaced aspects of the digital footprint of the home to make household computing routines and associated resources more visible. My goal with Kermit was to affect how users engage with the home network. In this chapter, I describe the motivation for making Kermit a probe as opposed to a fully fledged system. I then describe the design, implementation details, and evaluation of Kermit. Finally, I provide a summary of the findings from the field trial of the Kermit system.

5.1 Methods

I implemented Kermit as a technology probe to test out my empirically based design ideas—one of the many types of probes [10], first introduced by Hutchinson *et al.* [46].

I used a probe approach for the following reasons. First, I wanted to explore the design space around how the digital footprint could be surfaced. The most appropriate mechanism to do so was to provide my participants with a technology that they could engage with, which was not necessarily fully developed. Second, had I used a prototype that was more robust and developed, I would have solicited information about the learnability and usability of the system (e.g., feedback on the color of buttons, layout etc.) as opposed to feedback on the concept of the tool itself (e.g., would I use this type of tool?). Therefore, at this stage of research, to elicit design ideas and feedback on the concept of surfacing the digital footprint, I selected a probe approach.

Technology probes are meant to be simple, flexible and adaptable systems with 3 aims [46]. These aims include the social science goal of understanding real-world users needs and desires, field testing a particular scaled down version of a technology, and, finally, opening up the design space to inspire both the users and researchers to think of new technologies. For these reasons, creating Kermit as a probe allowed me to field-test the technological concept of a system for visualizing the digital footprint.

5.2 *Kermit*

5.2.1 Design Goals

My design goal for the Kermit probe was to learn how the household reacted to information about the home's digital footprint, i.e., computing routines and associated resources, and whether this increased visibility affected computing routines. For example, I sought to understand whether making this information visible would alter home occupants sense of technical self-efficacy or how confident they feel around network technology, change who manages and tends to the network, or change how household members use or regulate the network.

5.2.2 Surfacing Aspects of the Digital Footprint around Computing Routines and Resources

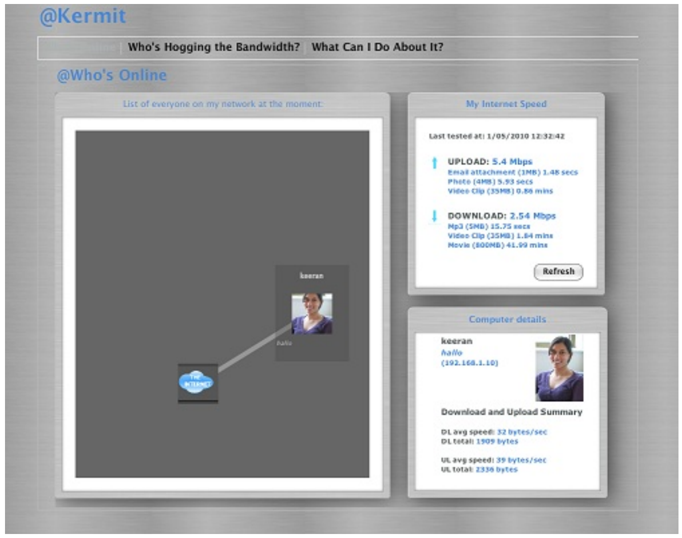
To begin to systematically examine how to surface the digital footprint—a vast amount of data—for my thesis, I scoped out a slice of the digital footprint data that I felt would be of interest to households. Rather than surfacing large collections of information tied to no particular theme, to solicit the most useful feedback on the Kermit concept, I chose to scope the aspect of the digital footprint I focused on to revolve around answering a particular question. I chose to make my question timely and relevant to current issues around home broadband and thus I chose to use the scoping question, "Why is the Internet slowing down?". The answer to this question was of interest at the time of undertaking this research to home consumers who need to know if they are getting broadband services for which they are paying. Moreover, this information could arguably help consumers determine why their broadband connections may not be at optimal speeds for household activities such as streaming media, web browsing or VoIP calls. My design goals for Kermit were to provide the following functionality to help users address this question:

1. Help users identify internal bandwidth bottlenecks

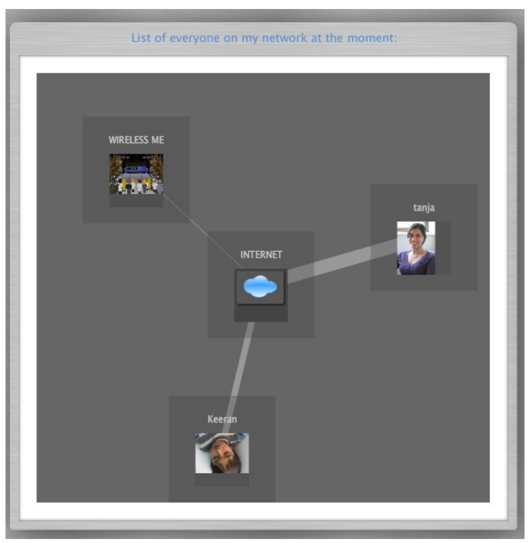
2. Help users identify external bandwidth bottlenecks

3. Allow users to take control over the bottlenecks

Kermit differs to other home networking tools which focus on network breakdowns, and troubleshooting alone rather than management in general. For example, Eden's [104] functional goals were to provide membership management for adding and removing devices from the network, access control for guests and parental controls for children. Eden also provided network traffic monitoring and a prioritize function for devices and applications. Although Eden has similar functional goals as Kermit, I specifically focused on surfacing information about bandwidth and Internet speed.



(a) Full screen



(b) Main View

Figure 11: Kermit's Who's Online Screen.

Figure 12: Kermit's Who's Online screen with right-click menu shown.

Unlike Eden, with my research I not only wanted to provide a functional tool but also to discover users mental models about bandwidth and Internet speed. My research further differs from Eden in that I chose to evaluate Kermit in a naturalistic setting rather than in a laboratory because this more closely approximates user experiences in the wild. Moreover, Kermit is concerned not only with showing what is happening with the technology in the home but also on capturing the socio-technical aspects of networking such as device owners. To make Kermit easy to use, I also chose to minimize user input, unlike in Eden, which required users to set up the room layout of their homes. To achieve the three design goals, I implemented Kermit as a set of screens corresponding to my three main design goals.

1. *Design goal of showing external network speed:* In the main "Who's online" screen shown in Figure 11, an estimated speed is shown from the Internet service provider, based on a custom speed test. This speed test is conducted automatically on the hour and can be refreshed on demand. Based on the speed, the number of seconds it would take to upload a 1 MB email attachment, 4 MB photo and a 35 MB video clip or download a 5 MB mp3, a 35 MB video clip or

an 800 MB movie were shown.

2. *Design goal of showing internal bandwidth hogs:* In the main "Who's online" screen, the user can see all the devices connected to the home network. Each device is depicted as a little box with a band connecting it to a central Internet cloud as shown in Figure 11(b). Each band goes thicker or thinner in near real-time depending on how much bandwidth that device is using relative to the other devices on the network averaged over the last minute. Each box can also be customized with an image, a text label and a status message. By default, a blue person icon is shown and the name of the machine displayed is the hostname of the machine. Double clicking on a device icon, brings up additional details on that computer such as an enlarged version of the name and image. Hovering over a device provides the bytes that machine has transmitted up and down over the last minute in a pop up. The details also include summaries of the upload and download bytes and speed for that machine over the last minute. In the "Who's hogging the bandwidth?" screen in Figure 13, users are also provided with a historical graph. This graph is a color-coded stacked bar chart for "Uploads" and "Downloads". Users can view time frames of "Last 10 minutes", "Last 1 hour" or "Last 24 hours" to visually see which color is dominating the charts. In the figure, Kermit dominates the uploads and downloads with an orange color.

3. *Design goal of providing users with agency to control their bandwidth:* To encourage user reactions about how they might control the network, I included the option to prioritize or limit any device connected to the network. To do so, users right-click the device icon and select "Prioritize this machine" or "Limit this machine" as shown in Figure 12. When a limit or priority action is applied, a textual annotation appears below the device's name, depicting either a "Limited" or "VIP". Using the same right-click menu, users can remove the

Figure 13: Kermit's Who's Hogging the Bandwidth? screen with right-click menu shown.

limit or priority. On the backend, the action sets a rule on the router to treat traffic and packets from the selected device as either higher or lower priority. This rule is removed when the removal action is undertaken.

A final screen (shown in Figure 14) called "What can I do about it?" provided textual reminders about how to use Kermit and my phone number in case of problems.

Kermit logs basic information about the network over time when any user has the Kermit screen up. Logged data included information about how much bandwidth each device is using at the time, automatic speed test results and if the user renames devices, limits or prioritizes machines, or changes photos. I logged this data to detect trends in usage over time and to provide a triangulation point and discussion starter in the post-study interviews. Usage was only tracked as a whole, so usage from individual devices could not be detected due to the way the logging was set up.

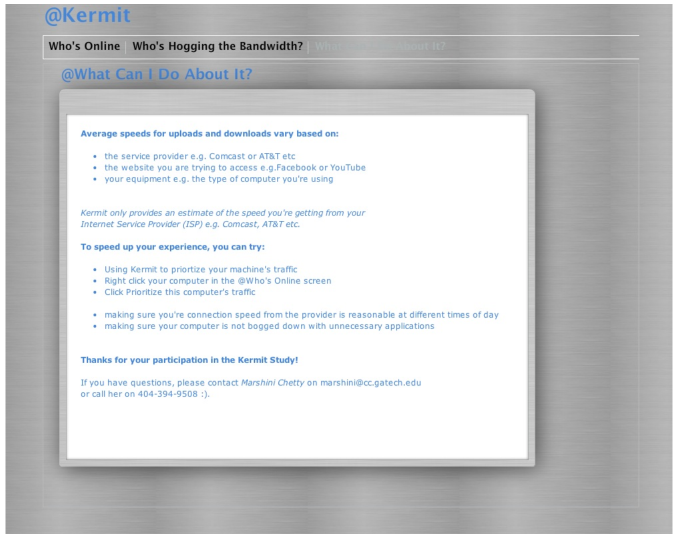


Figure 14: Kermit's What Can I Do About It? Screen.

5.2.2.1 Basic Kermit Architecture and Design and Requirements:

I designed Kermit to use information that is available from consumer routers. Routers are excellent sources of network information because all traffic passes through this device and they also have basic information on all devices connected to network. One drawback of being dependent on the router for information, is that if the router is down or cannot see a device (and vice versa), some information loss can occur. However, this implementation decision is arguably more efficient than having a separate Kermit application running on each device, tracking an individual device's information and trying to pool information from other devices on the network. Ideally, a fully fledged system would run on the router or would be an interface for the router, which has an overview of all devices on the network and therefore access to much of the information in the digital footprint. The technical details of Kermit are discussed in Appendix A.8.

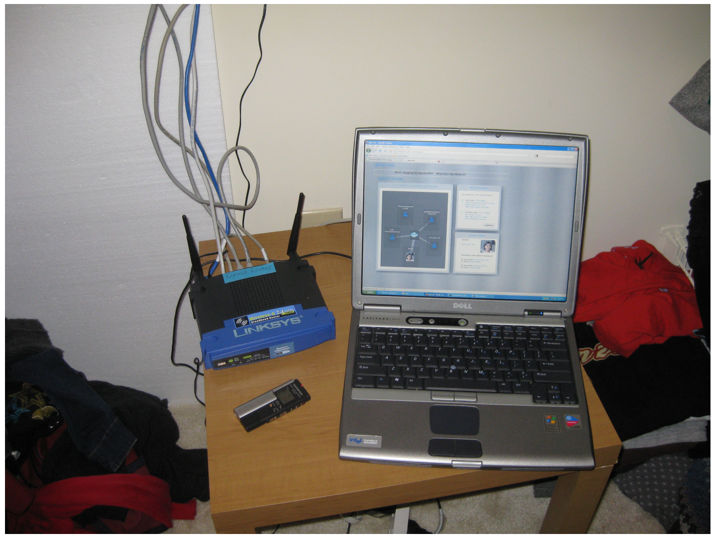


Figure 15: A Kermit deployment in a participant's household showing the laptop with the server and the Kermit router.

5.3 Deployment Overview

During the field trial, Kermit was deployed as a web application on a server machine (a Dell laptop) connected to the home network's router. The Kermit interface was accessible via a standard web browser. To access Kermit, users could surf to the Kermit URL from any device connected to this router, both via wired connections or wirelessly. Deploying the system involved installing my own custom router for the duration of the study, and leaving a server laptop in the participant's household for 2 weeks at minimum as shown in Figure 15.

5.3.1 Pilot study

To test the probe for robustness, I conducted a pilot study of Kermit, beginning in December 2009 and continuing into February of 2010 with two households. One pilot household comprised two roommates and the other household was an unmarried couple. By doing a pilot, I was able to ensure that my protocol would return appropriate data and that the Kermit probe was robust. A picture of one of the pilot deployments is shown in Figure 16.

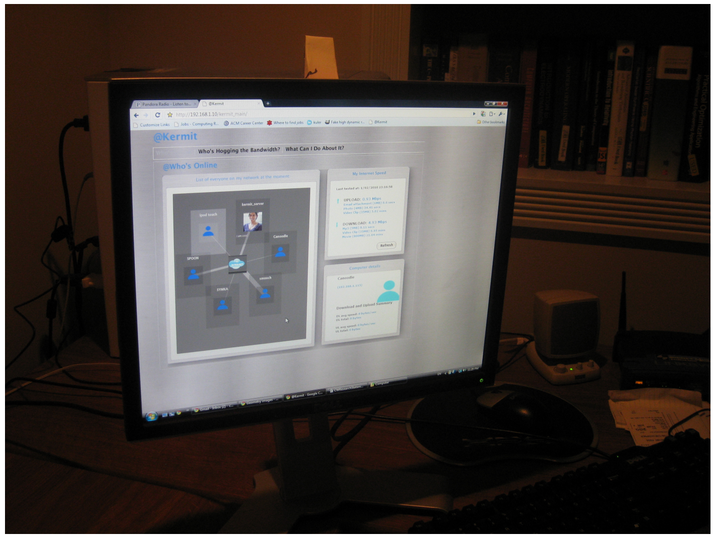


Figure 16: Kermit running in one of the pilot households.

5.3.2 Participants

To fully evaluate the Kermit technology probe, I recruited ten households in the Atlanta and surrounding metropolitan areas to participate in a field trial. I ran these households in batches to allow me to gather data and analyze data from a set of households before moving onto the next batch. Interspersing data collection and analysis allowed me to refine my questions during the study and ensure I collected all data points of interest. I recruited households through word of mouth and email lists. Each household was given a $100 gift card at the end of the study as compensation for their time. I visited each household a minimum of three times, with additional visits being added on an ad-hoc basic when households required technical support during the study.

Participant demographics are summarized in Table 5. Household 4 had to be dropped from the study because their DSL modem would not recognize the Kermit router, because of configuration difficulties with DD-WRT [22] and a Motorola modem. I have not included their data in my final analysis. I interviewed couples, roommates and families with children to complement the data sets gathered from my previous studies. Participant occupations ranged from stay-at-home dad to firefighters and graduate students. The technical background of individual household members was varied.

Table 5: Participant demographics for the study conducted in Spring 2010.

Household	Participant Demographics
H1	H1P1, M, Project Coordinator, 27, Roommate H1P2, M, Pharmacy Technician, 27, Roommate H1P3, M, Package Company Supervisor, 28, Roommate
H2	H2P1, F, Usability Analyst, 32, Wife H2P2, M, Firefighter, 40, Husband
H3	H3P1, F, Usability Analyst, 30, Girlfriend H3P2, M, Self employed, 36, Boyfriend
H4	Had to drop out of the study
H5	H5P1, F, Consultant, 46, Mother H5P2, F, Scholar, 18, Daughter H5P3, F, Scholar, 13, Daughter
H6	H6P1, M, Homemaker, 40, Father H6P2, F, Insurance, 40, Mother H6P3, M, Scholar, 15, Son H6P4, F, Child, 4, Daughter H6P5, M, Child, 2, Son
H7	H7P1, F, Therapist, 31, Girlfriend H7P2, M, Business Consultant, 37, Boyfriend and Father H7P3, M, Scholar, 16, Son
H8	H8P1, M, Graduate student, 25, Roommate H8P2, M, Graduate student, 25, Roommate H8P3, F, Graduate student, 26, Roommate
H9	H9P1, F, Graduate student, 23, Sister H9P2, M, Software Engineer, 26, Brother
H10	H10P1, M, Software Engineer, 43, Father H10P2, F, Usability Specialist, 46, Mother H10P3, M, Scholar, 8, Son H10P4, M, Scholar, 5, Son
H11	H11P1, M, Graduate Student, 27, Partner H11P2, M, Musician, 27, Partner

5.3.3 Methods

An overview of the study is shown in Table 7. In the first visit, I gathered baseline data about my participating households' computing routines. During this visit, participants were asked to sketch out their home networks, answer a demographic survey as well as a pre-study Kermit questionnaire to assess familiarity with broadband concepts such as bandwidth and elicit information about occupants' home network roles. During this time, I also interviewed all the household members. At the time of working on this dissertation, broadband debates about net neutrality or creating tiers of Internet usage for different prices were ongoing. As such, I found that it was timely to question participants about their wider knowledge of broadband debates, such as net neutrality and tiered services.

I approached this line of questioning as follows. I first asked participants what they knew about net neutrality and tiered services. If they had heard of these issues, I solicited their take on the debates. If they had not heard of the debates, I outlined the for and against argument of the debates and solicited their feedback. I understand that at this point, I may have introduced personal bias into the interview, but I took care not to cast any of the explanations in either a positive or negative light. In addition, I also asked about these issues in a written survey to help me triangulate data I gathered from the interviews. I chose not to install Kermit on the first visit for several reasons. First, I wanted to build up rapport with my participants before asking them to replace their router with my own custom router. Second, to reduce the time to conduct the interview I wanted to gather baseline data before having to use up one to three hours of time on installation activities. Third, although in retrospect, it may have been useful to collect network traffic data prior to showing users the Kermit interface, since changes in network traffic were not the focus of my study, I chose to instead install Kermit on the second visit.

In the second home visit, I installed the Kermit system by replacing the household router with my own and leaving a server machine in the home for a period of two weeks minimum. During this visit, I explained how Kermit worked and left the household members with “Kermit Homework Tasks” for each week of the two week deployment period. Each homework task, shown in Table 6, was designed to be lightweight and allow each user to try out the different functionality afforded by Kermit, to facilitate the feedback process. Each participant was given a list of the tasks and a column marked “Date Completed” to indicate when they performed the particular task. Each set of tasks could be completed in 5 minutes or less. I provided the tasks so that participants would have feedback regardless of how often they used Kermit, given that I was interested in the reaction to the tool’s concept. In the third and final visit, I uninstalled Kermit, administered a post-study Kermit survey and interviewed all household members. I audio-taped all the interviews and took photos of relevant artifacts, home networking equipment and the house exteriors.

Table 6: Overview of Kermit Tasks.

Week	Task
1	Who’s the biggest bandwidth hog in your house today? Change your computers picture on Kermit What upload speed are you getting today? Prioritize your computers traffic for an hour
2	In the last hour, which computer did the most uploads? Change your computer’s status message How long would it take you to download an mp3 today? Limit a computers traffic for 30 minutes

5.3.4 Data Measures and Analysis Overview

An overview of the data measures I collected is shown in Table 8. I used a grounded theory-inspired method [93] to analyze the transcribed interviews, with the assistance of two undergraduate assistants. With these students, I coded the data for emergent themes and discussed recurring issues of interest. I then recoded all the data based

Table 7: Overview of Kermit Study.

Week	Visit	Measures
1	Home visit 1	Baseline information gathering Introduction protocol Observation of current setup Pre-Kermit survey Demographic survey Home network sketches Initial interview
2	Home Visit 2	Kermit installation Administering Kermit homework
4	Home Visit 3	Exit protocol Uninstall Kermit Post-Kermit survey Final speculative sketch

Table 8: Overview of Kermit Measures.

Measure	Details
Semi-structured interviews	Interview questions focused on computing routines, roles, net neutrality, tiered services and Kermit.
Logs of Kermit use	Usage data was logged when the Kermit screen was up.
Diaries of use	User logged their Internet usage for a week noting periods when the Internet was slow.
Demographic survey	This survey captured basic information such as age, occupation, income level and technical background.
Pre-Study Survey	This questionnaire was geared towards identifying how comfortable each household member was with the home network and what their roles were with respect to the network
Post-Study Survey	This questionnaire was geared towards gathering feedback on Kermit and determining participants' understanding of complex concepts such as bandwidth.
Pre-study Sketch	In this diagram, users drew their understanding of the home network.
Post-study Sketch	In this diagram, users drew speculative sketches on interfaces for bandwidth monitoring that they would like to have.

on our agreements using the qualitative data analysis tool Atlas.ti. I digitized all my survey and sketch data and analyzed the diaries of Internet usage. I also calculated basic descriptive statistics from the surveys and analyzed the database logs using SQL queries. To form a holistic view of the data, I triangulated data from all the data sources and developed an overall picture of the results, which I discuss next.

5.4 Results

I discuss my results under four main themes, and I present data from all of my measures (as shown in Table 8) where appropriate. First, I describe the baseline data collected before I introduced Kermit. My baseline data includes data on my participants' awareness of broadband issues, such as knowledge of their Internet speed, their arguments for, and against broadband issues such as net neutrality, and their attitudes towards paying for web content. Next, I discuss Kermit's role as a broadband management tool. Specifically, I describe how participants responded to the probe to visualize the home network, diagnose a slow connection, identify bandwidth bottlenecks and manage their speeds. Finally, I discuss how my participants perceived Kermit to be a technological consumer watchdog.

5.4.1 Awareness of Broadband Issues

To discover existing knowledge about broadband issues and how visible the digital footprint is to households, prior to installing Kermit, I asked about what participants knew about concepts such as bandwidth and broadband. My results revealed that participants had very little prior knowledge about factors causing their varying connection speed. For example, many households suspected that household members were hogging the bandwidth. Others felt that their service providers might be the cause of Internet slowdowns. From the survey data, I found that just under half of the respondents had never performed a speed test before. Additionally, half of the participants did not know what speed package they were paying for. Yet, over two thirds of the participants agreed that they would like to know their Internet speed to see if they were being charged too much.

Before I introduced Kermit, I also noted a distinct lack of trust in Internet service providers. For instance, a firefighter in household two declared of his ISP:

> H2P2: "I mean it's hard to know what you're supposed to be getting. And whether or not they're actually telling the truth is a whole other story."

His view was echoed by a young project coordinator who told me:

> H1P1: "Comcast offers those three different packages, three different speeds, and I don't really necessarily trust that any of them are really faster than the others."

Aside from speed concerns, my participants, similar to users in my formative studies, wondered if their networks were secure. For instance, the firefighter said:

> H2P2: "That's our wireless router, and like I said, the only way I can know if anyone is on there...I can come down here. And it's got up to four [lights], and right now the only one that connected is hers. If I'm on, the second one will light up. If someone else is on, the third and the fourth."

Similarly, a mother of three wondered:

> H6P2: "I'd like to see if someone unauthorized can get into our bandwidth usage. In other words, somebody sucking up our air without our knowledge."

Once I had asked about the basics of participants' understanding of their Internet speed and speed tests, I moved on to ask them about tiered Internet services. I describe the results of this inquiry in the next section.

5.4.1.1 Consumer Attitudes for Net Neutrality

My results showed that more than half of my participants (57%) had never heard of net neutrality. Even of those that had, most were not entirely clear about what the debate was on or what the effects of a non-'net neutral' policy would have on them. Once more informed on what these debates entailed, participants had strong opinions of their own. Unsurprisingly, all the participants were supportive of the current policy, citing reasons such as

> H8P1: "I support net neutrality. The Internet wants to be free. Free as in speech, not as in beer."
>
> H1P1: "It's ludicrous to have to pay different things for different data. . . Well, for me, it would be like charging for different power stations that are all feeding into your electricity, and you have to pay a different rate based on where it's coming from locally. It should be a utility, and it should be regulated like a utility."
>
> H1P2: "That's pretty much an ingrained entitlement at this point. Like the question, 'Would I ever pay for YouTube or Google?' It's just the Internet. It's free exchange of information. That would defeat the purpose."

Along with strong support for net neutrality, my participants were wary of ISPs abusing tiered services. For instance, a mother of two worried that a tiered service could shut down access to certain sites. She and a software engineer provided the following examples:

> H10P2: "But the things that concern me that I hear going on about net neutrality. There are some sites, especially, I think ESPN's site, for example, that are only accessible if you are with a particular ISP, and that's a problem."

> H9P2: "I think it's too prone to abuse, especially when most ISPs have a local monopoly... Yeah. I mean, they could charge too much or even flat out censor or block sites if they were able to. And since there's no competition around there's nothing really stopping them from doing that."

My data also indicated that aside from worries about abuse by ISPs, participants felt that tiered services could stymie the accidental discovery of new information typical of browsing the web. For example, a step-mom in her thirties told me:

> H7P1: "I think I'd rather be net neutral. I think it would prevent you from exploring web sites that you would never go on... Right? Like, I think people are much more apt to like search the web and go someplace new or different if everything is equally accessible."

In all, what was clear was that before I introduced Kermit, participants did have thoughts to add about the net neutrality debate once they were informed about what the debate was. Next, I discuss what arguments participants made against net neutrality.

5.4.1.2 Consumer Attitudes Against Net Neutrality

I noted that there was definitely consistent support for net neutrality. However, my participants did express views on the fence about the finer details which were not wholly supportive of the current net-neutral policy. For example, several participants felt that network neutrality is not sustainable because the underlying infrastructure requires maintenance and upgrades:

> H10P1: "If they ever do enforce net neutrality, no one is ever going to make an investment in improving the network. Because there is no pay off. So it's like well ok, if it is going to kill innovation, or it's ... This stuff isn't free. This stuff doesn't build itself. It doesn't maintain itself. So where's

> that money going to come from unless the government starts subsidizing and we're just back to the same federally mandated or regulated across everything."

This participant explained further, using an online streaming media company called Netflix as an example to show where a non-neutral network could be useful:

> H10P1: "I'm a Netflix customer, I only have 1.5 [Mbps], but Netflix pays extra to deliver stuff at 6 megs to me under the hood.".

Along with this view, several other participants argued that a tiered service might be more fair, comparing it to cable TV. For example, one self-employed participant, a thirty six year old male said:

> H3P2: "From a consumer standpoint, it has its benefits just like cable. I never watch Nickelodeon. Why should I have to be paying for it? Even if it's not a line item, I know it's in there, and somehow I'm paying for it? I never go to MySpace. Why should I have to pay for it?"

To sum up, participants were not unilaterally opposed to a non-neutral network. The higher-level takeaway is that regardless of their opinions, participants had opinions when they were informed enough to provide their own input. In the next section, I elaborate on responses to paying for online content in a tiered service model.

5.4.1.3 Attitudes to Paying for Online Content

When asked on the survey, my participants expressed objections to the idea of paying additional fees for the privilege of using certain sites. For instance, 70% of respondents did not want to pay a separate monthly fee for any one of the services: Google YouTube, Skype, Facebook, Flickr, or Hulu. Participants were more evenly split on whether paying a fee for a bundle of sites was acceptable with 55% of survey respondents willing to pay a fee for an inclusive package of web sites. Despite these responses, participants were not entirely opposed to paying for content provision services such as ABC.com.

The following quote illustrates this:

> H1P1: "And when it's a service like Netflix or something like that where you're getting stuff that people produced and made, and you're doing it for your own entertainment, don't have a problem."

Another participant shared this sentiment:

> H5P1: "I mean if you wanted to access certain YouTube videos I understand charging for that. But I don't think as a whole, charging for different bundles [is ok] because the Internet is kind of known as free."

Several households were on the other end of the spectrum, and told me that they might prefer switching to a pay-per-use model of bandwidth. The reasoning provided is illustrated by the following quote from a graduate student in his twenties:

> H8P2: "I'd just prefer to just pay for my bandwidth rather than having different prices for different services."

To reiterate from the previous section, all my participants had strong opinions about the issues once I explained the basic premise. And yet, few were aware of or used tools available at their disposal to help protect their rights as consumers. Many did not even know how to check whether their actual speeds met the advertised ones. Thus, it quickly became apparent from participants' knowledge of broadband issues that tools that make usable information about home broadband speeds more visible, are fast becoming a necessity.

5.4.2 Kermit as a Broadband Management Tool

I now turn to a discussion of how Kermit the probe was received. My data revealed that Kermit was used beyond the homework tasks I asked my participants to undertake. Specifically, of the ten households, eight completed the homework tasks and all provided feedback about the probe. On average, based on eight intact database logs (two were corrupted), Kermit was running in each household for twelve days on average, with an average of 21 automated and user run speed tests per day. During the deployment period, each household used the limits and prioritize functions for their machines at least three times each. Each household accessed the history pages for the last ten minutes activity on average seven times, for the last hour on average six times and for the last day on average five times. Overall, I found that Kermit was used as a broadband management tool in four ways: to visualize their home network, allow users to diagnose slow speeds, determine bandwidth bottlenecks, and manage their broadband connections. I discuss each theme in more depth.

5.4.2.1 Visualizing the Home Network

Generally, my data indicated that participants found Kermit easy-to-use with one teenager going so far as to say:

> H5P2: "I think Nana [her grandmother] could use it."

In particular, participants told me they liked being able to access Kermit from any browser, as opposed to having a standalone appliance. They felt this simple mechanism allowed them to check Kermit whenever they wanted. The most popular feature of Kermit, as suggested by my data, was the household view of machines and networked devices in the home. Eight participating households changed the icons for and renamed all the machines in their network, despite only being tasked with doing this for one machine. Names were either descriptive of the machine such as "Xbox", "Small Netbook" or "iPhoney" or included the owner's name and machine type, for instance, “Matt’s Desktop”. Other labels were nicknames or “funny” names including “snoop” to depict an unidentified machine.

Participants also associated pictures with their icons. These images varied from personal photos of device owners to cartoon characters or famous people. Several participants changed the icon for the Kermit machine to Kermit the frog from the American children’s program “Sesame Street”. In each case where participants changed their pictures, they chose images to be “funny”, directly represent the person in question or a particular machine with a local household reference or inside joke. The status messages that participants put up varied from expressions of emotion such as, “iHappy”, to greetings (e.g., “hi”) or messages about activities (e.g., “Really Choking” or “I am the great Internet hawg”) and finally declarations about the self (e.g., “Too Awesome!” or “The King”.)

Participants liked these minor personalizations because they allowed them to form a clear picture of their household’s home network. In some cases, participants felt more secure as the following quote illustrates:

> H2P2: “Because you can change the pictures, you know that ‘Hey, that person, that computer is not ours’, ‘It doesn’t belong’, ‘It’s not part of our family’”

During the study, one of my participating families actually discovered someone unauthorized was using their wireless Internet. From glancing at the Kermit ‘Who’s Online’ screen, they saw an unknown computer when all their devices were already accounted for. In the words of the mother:

> H7P1: “Now I know there’s a little mouse on the Internet. On our Internet, stealing our Internet.”

Aside from making participants feel that their networks were secure, in some ways, Kermit made household members feel more connected to each other. These participants saw Kermit as conversation piece. This Kermit effect was exemplified by a participant who lived with her brother:

> H9P1: "It's kind of like a community feel. Like what is he doing? What have you been uploading? What are you downloading so much of?. . . But it's interesting just to see. Maybe I could make a joke to him."

To summarize this section, my data suggests that participants found Kermit easy to use and understand. My study participants' took time to personalize their representations and this action helped them form a clear picture of their home network. Participants also used Kermit to express their identity to others in the home. For these reasons, Kermit was a precursor for an internal household social network. The data implies that other tools like this can indirectly facilitate family coordination, conversation and social relations. Next, I discuss how Kermit was used to diagnose a slow connection.

5.4.2.2 Diagnosing a Slow Connection

For several participants, my data showed that Kermit confirmed they were getting the speeds they were paying for, as illustrated by these quotes:

> H9P2: "It did. I mean I thought we were getting pretty good speeds and it quantified and confirmed what I suspected so."
>
> H6P1: "We're paying for 12 Mbps high-speed. I pay you know, 25 bucks a month. Literally 25 dollars a month. And it's a separate bill. I know, for the most part, right on the spot I've gotten 12 or better every day. So that much I do know from looking at the Kermit system."

My participants also learned other things about their broadband connection. One participant, for example, discovered that his Internet speed varied from hour-to-hour. In another instance, a participating stay-at-home dad told me:

> H6P1: "I did learn that bandwidth just isn't about uploading and downloading. It's a lot more. It's not what I do by myself, it's what everybody in the house does. And it's not just the little bit of difference that I make on my computer. It's the collective and being able to put all that together, that was really cool."

Although my participants learned more about their Internet speed, several were confused about the types of information shown. For instance, a usability analyst, was not sure about the difference between "the total pipe coming into the house" from the provider, versus what speed or bandwidth each computer was getting. This participant categorized the different notions of speed according to her mental model:

> H10P2: "You had those three things so it's the household speed, what's maximally available at a given time. And then how it's been allocated. And then what my current usage of it is."

My participants also desired more context about the quality of the speed they were getting in addition to information about how their actual speed compared to their advertised speed. For example, a female therapist, suggested a rating system for the speed similar to the U.S. financial score of credit worthiness. Others suggested that a color-coded indicator or having an anchor point in the display for the average speed would provide more detail about how 'good' a particular speed is.

More importantly, my data revealed that participants were not sure what recourse they would have, armed with Kermit's information. Essentially, most participants lacked confidence that their service provider would take action if they were alerted about the mismatch between actual and advertised speeds. Finally, with respect to the speed tests, several participants expressed dismay and complained that the automatic speed tests were somewhat intrusive. Specifically, the tests occasionally disrupted normal browsing activities because of the need to upload and download a large file. A clear improvement to a tool like Kermit might therefore be an option to more easily set the parameters of any speed tests, such as how often and when they occur.

To summarize, Kermit's visualization definitely provoked thought about why connections might be slow and participants were receptive to the information. However, participants clearly needed more information to help them understand complex concepts such as bandwidth and Internet speed. Next, I discuss how Kermit was used to identify bandwidth bottlenecks.

5.4.2.3 Identifying Bandwidth Bottlenecks

Participants liked the real-time bandwidth visualization to see

> H2P1: "How much juice everyone is getting"

The following quotes from a teenager in high school and a student with a design background further illustrate this point:

> H5P2: "I found myself actually checking it while I was online to see when mommy was down here on the computer. And I'd be upstairs doing homework, to see who was using more bandwidth".
>
> H11P1: "When I did the bandwidth hog test, it was me by a mile because I had five YouTube windows up and those use a lot."

For others, the information was surprising. This was evident in the case of a parent in household six who discovered he was the biggest hog despite suspecting his son of using the most bandwidth. Participants also learned more about the bandwidth usage of different devices:

> H1P1: "I was really, really surprised by how much bandwidth the Xbox takes relative to other things. I think it may just be that it's consistently being used, whereas other machines are sitting around a lot."

Not only did participants enjoy the "Who's Online" screen, they also suggested several improvements to the bandwidth visualization. For example, a mother of two told us:

> H10P2: "There's nothing explicitly shown about remaining bandwidth. I mean do I have an excess right now or is everything being pegged? So something like that. Is there any to spare right now? Versus no everything is being maxed out."

To address this concern, showing the sum of bandwidth as slices of a pie might better fit in with users' mental model of how bandwidth is dished out in the home. Another common improvement suggested is typified by the following quote:

> H6P1: "If somebody is sucking up a little bit more bandwidth, maybe they need to rotate up to the top so that you see who's got the priority on sucking the bandwidth right now."

Participants also repeatedly told me they wanted to see bandwidth use by applications (e.g., Skype versus Facebook). Information on application bandwidth use could help users decide which applications to shut down to speed up their connection. In addition, participants suspected they could identify whether machines have been compromised. For example, high and unusual traffic on a machine may indicate that it has a virus, or someone has infiltrated the network.

In general, my participants found the historical information less useful than the real-time visualization. In several households, the history views displayed the Kermit server machine as the main bandwidth culprit due to a software bug—a common challenge in deployment studies. Even with this bug, all my participants were able to easily identify the bandwidth hog in the color-coded stacked graphs. Moreover, my participants were still able to learn from the history views. For instance, a participating software engineer managed to identify that uploads caused significant bottlenecks:

> H10P1: "I actually did learn something. Basically doing uploads actually greatly affects overall experience. Or basically has the biggest effect on the network in general-At least going to the Internet"

To sum up, my data suggested participants were able to learn from the bandwidth information provided. Participants were also able to provide feedback on how to improve the display, such as providing information about left over bandwidth or having a history of speed tests to plan when to go online. Some also mentioned having a history of network connection drops would be useful for discussing service disruptions with the Internet service provider. In the next section, I discuss how Kermit was used to manage the broadband connection.

5.4.2.4 Managing the Connection

My database logs showed that participants made use of the limit and prioritize functions and they also spoke of using them in my interviews. In particular, participants enjoyed the concept of prioritizing a machine's Internet traffic:

> H6P1: "I think that limiting and prioritizing are great. Having general control for just an average user is a good option, having a bit more detailed control over it for an advanced user great option as well. And there again, like I said earlier, having the option to totally cut somebody off or setting up a time restriction. And being able to throttle it down to zero for Internet usage overall."

In household two, a wife limited her husband's machine and prioritized her own because she worked from home. Similarly in household six, a father limited his son and ensured his work machine was the "VIP" because he suspected his son was using up too much bandwidth. In household seven, a business consultant working from home limited his girlfriend's machine and his son's Xbox and prioritized his own machine.

Although participants used the limit and priority functions in Kermit, many neglected to undo those actions because they forgot they had applied them. In one case, a mother had limited her daughter's machine because she believed this would slow down her time on Facebook and had forgotten about it. This example shows that it is tricky for users to develop an accurate mental model of something as dynamic and varying as bandwidth and Internet speed. Additionally, this example shows how participants easily forget they have applied limits or priorities.

To remedy this situation, participants suggested that there be a notification for the person being limited or the limiter. Another improvement suggested was that any limit or priority should expire. Users also suggested that popping up a notice saying that Machine X is about to be unlimited/de-prioritized with an option to renew the limit or priority would be a helpful reminder.

Participants also wanted to schedule priorities and limits much like a thermostat. One father of two suggested that Kermit should allow families to create different groups of machines to denote childrens', parents' and household devices such as media centers. He envisioned these groups could be treated differently depending on the time of day. He talked about prioritizing a media center when the family is watching a movie and similarly, prioritizing a backup machine late at night. In fact, all of my participating parents requested that there be a mechanism to shut off access completely to the Internet on a particular machine. Specifically, parents wanted to control Internet access and schedule when their kids could go online. In some senses, Kermit was therefore seen as a tool for what Rode describes as "digital parenting" [79].

My participants did not always know what exactly the limit and priority actions did. They also expressed confusion about how multiple machines could be "VIP"s or prioritized or how these slots are determined in practice. Moreover, without a perceptible effect after applying a limit or priority, participants did not know how well Kermit was working. A quote from a software engineer illustrates this frustration:

> H10P1: "I don't think prioritization was actually working or I could not observe an effect. If I was running traffic, I'd set the machine with priority, or not priority. And it was still running traffic on another machine and my responsiveness was still good".

Others, who were less technically inclined, were content even with a placebo effect:

> H8P3: "Psychologically, it's kinda nice to just click 'Prioritize my bandwidth'. And it's one more thing I can do to make my Hulu video load more smoothly."

In summary, my participants enjoyed being able to take control of factors influencing their broadband. They particularly liked the ability to prioritize machines more so than the ability to limit machines. Overall, participants wanted more control over the parameters for setting priorities and limits. Additionally, participants desired a perceptible or visual indication that an action was having an effect. Now that I have discussed how participants viewed Kermit as a broadband management tool, I will describe how Kermit was seen as a precursor tool for a broadband consumer watchdog.

5.4.3 Kermit as Consumer Watchdog

I did not design Kermit for protecting consumer rights but this theme came out strongly in the data. In one in depth example, a participant in his twenties, a project coordinator at a research institute told me of the hassles of getting his service provider to fix network drops. He recounted hours on the phone being shunted between the manufacturer of the router he purchased and the cable company, as they sought to determine why his network connection was not working. In addition, he complained of how his service provider always ran their own tests on his line and never picked up problems even though his network connection was faulty.

In my last home visit with him, I serendipitously observed him on a hour long technical support call. At this time, I witnessed first-hand how difficult participants find it to communicate details about the nature of their connectivity problems to their providers. For him, and other participants, having a log of network drops or a neutral speed test in Kermit would be good fuel for discussions with service providers. In particular, such information would be useful for troubleshooting and protecting the consumer. He explained:

> H3P2: "But, you know a lot of times they'll say. . . you know you'll have connection issues and stuff. And you'll just call them and they'll say, 'Well, I tested your connection and it's fine right now.' But, you know if it's a re-occurring problem, then if you have a log of 'Yeah, we went down at this time.' We went down at this time. We went down at this time. And there's something that keeps track of it, then I think you'd just be more likely to be able to get support if you have that. Rather than just saying, 'Yeah, my Internet connection goes out all the time'.".

Other participants also echoed the idea of a consumer watchdog tool to help identify the source of Internet slowdowns so appropriate actions could be taken. For instance, deciding to call the ISP, shutting down offending applications or limiting a bandwidth hog. Essentially, often a big unknown was the source of a network speed or broadband problem:

> H5P1: "Like when [my daughter] can't get on the Internet and I'm on the Internet, why is she not getting on? What is there a problem with the [ISP] server or is there a problem with the router or is there a problem with her computer?"

In addition to knowing the source of the problem, participants also wanted to be able to print or email a record of Kermit's collected data to their ISP either to complain about their service or help the provider solve their problems. In sum, my data suggests participants viewed Kermit as more than a tool for managing broadband connections. For them, Kermit was a trusted instrument for providing valuable information on whether they were getting advertised services. To further develop Kermit along this line, allowing sharing of the information it collects would make it more useful for helping households communicate with their service providers. In the following section, I summarize the results of my field trial.

5.5 Summary of Findings

In the field trial of Kermit, I found participants were not aware of broadband issues which were external to their homes. This was surprising to me because these issues such as net neutrality will have a direct effect on their day to day Internet habits. Yet, I did find that participants were keen on having their rights as consumers protected at all costs. After I introduced Kermit, participants were able to learn about their speed and security. Kermit, as my data suggests, allowed visualization and personalization of their home network.

Additionally, participants were able to exercise direct control over how bandwidth is used in the home. In particular, my participants embraced the concept of prioritizing machines and found a browser based application more useful than a separate appliance. More interestingly, Kermit was also seen as a consumer watchdog, especially because of ongoing debates about broadband issues in the home. Overall, the field trial with Kermit has definitely inspired design ideas for making infrastructure more visible which I discuss further in Chapter 6 along with ideas for future home broadband management tools in Chapter 8.

5.6 Chapter Summary

In this chapter, I have described the design, implementation details and results from the field trial of Kermit, an empirically inspired technology probe for surfacing the home's digital footprint. Recall my final research questions from Chapter 1:

How will surfacing invisible aspects of the digital footprint cause changes in households' engagement with home networking infrastructure? Specifically will the following user engagements change as a result of interactions with Kermit, a technology probe for surfacing aspects of the digital footprint based on findings from RQ1 and RQ2:

- *RQ3.1: Change users sense of self-efficacy with respect to the home network*
- *RQ3.2: Change computing routines and the awareness of resources users use e.g., Through increased problem solving, increased awareness of bandwidth, time spent on computing routines or via other emergent behaviors*

My results suggest that having information about the digital footprint made more accessible and visible to end-users does affect levels of technical self-efficacy in the home. For both technically savvy and non-expert users, simplifying the interface to broadband management helps users learn more about abstract concepts such as bandwidth and gives them a sense of control over their Internet activities. Participants also changed their computing routines after learning more about their network, e.g., that uploads are slowing down the network. In the next chapter, I will discuss the overall reflections from the thesis work.

CHAPTER VI

RECONSIDERING NETWORKED INFRASTRUCTURE

In this chapter, I discuss the overall themes emerging from my research. I set out to study how surfacing invisible aspects of infrastructure would affect user engagement with that infrastructure. Specifically, I examined the home network as a case study of infrastructure. Through empirical work, I identified that the digital footprint of the home, the collection of information flowing through the home network, is largely invisible to end-users. By designing a technology probe called Kermit, I was able to visualize one aspect of the digital footprint to users to see how it affected their perceptions of their home network.

Based on this research, I first discuss expansions to the Kermit work by describing limitations and design suggestions for creating future broadband management tools. Next, I discuss how the fundamental criteria of making infrastructure visible is crucial for making intelligible and accountable network infrastructure. I describe how this increased visibility or *inspectability* can be achieved and provide a framework for thinking about factors to consider when designing an inspectable infrastructure. Additionally, I discuss how inspectability fits within debates on privacy, and surveillance in HCI. I conclude the chapter with a brief summary.

6.1 Designing Broadband Tools for the Home

In this section, I describe the opportunities for future work in the area of broadband tool design. I will return to a deeper discussion of future work in Chapter 8. In the field trial of Kermit, users suggested that several practical improvements could be made for designing future household broadband management tools:

1. *Scaling Visualizations:* Kermit was reported to be quite cluttered, particularly when households had many devices. As a home network evolves when devices are added or removed, a broadband management tool should have a robust enough visualization to scale up or down to include as many devices needed.

2. *Personalization:* My empirical evaluation of Kermit showed that users really appreciated being able to personalize a representation of their home network quickly with text and images. Helping users personalize representations in future tools could further scaffold understanding of a home network layout as they are easily able to identify devices and owners. Personalization also helps them form a mental model of the social map of the home superimposed on the technical map. In other words, a machine is not just the Xbox or the laptop but "Mom's laptop" or "Dad's Xbox".

3. *Scaffolding Understanding By Providing Context and Comparisons for Complex Concepts:* My field trial of Kermit showed that users did not always understand the differences between the concepts of uploads, downloads, bandwidth, and speed. Fundamentally, these are difficult network concepts to grasp, regardless of one's technical knowledge. However, for the average user, providing more context around each concept may help households learn more about the aspects of these concepts which are relevant to their usage patterns. For example, knowing that the current speed is above or below average speed for a particular neighborhood or provider could help users understand whether they are getting the services they deserve. Users may also better understand variances in connection speed over time.

4. *Making the Effects of Action Visible:* With Kermit, users were not convinced that the limit or prioritize actions were affecting their network speeds on those machines to which the action was applied. In broadband management tools,

because of the variances in speed and bandwidth, showing users a perceptible difference in performance may be difficult. Yet users need to know that their actions in a tool are having an effect. Moreover, giving users control over when network disrupting activities such as intrusive speeds tests occur is necessary to help minimize interruptions to online activities. For some, having the option to schedule network monitoring activities or priorities and limits was especially appealing.

5. *Empowering the Consumer as an Individual and Collectively:* In my study, users saw Kermit's potential for empowering them in dealings with their service providers. It also became evident that having usable household broadband management tools can serve to educate consumers about the issues at stake in broadband debates. For a broadband tool to fulfill this role, showing the speeds that a consumer is paying for as compared to the current speed can help users learn more about their providers' performance. Also, sharing the data beyond a single household is crucial to help policy-makers and legislators become better informed with respect to broadband debates. If households can opt in to contribute data to a publicly available central pool, this data pool could potentially improve service if ISPs feel more accountable for the quality of their service provision. Moreover, even just allowing data sharing between the provider and the home would help households show providers when the network drops, if their speeds are on par with what they are paying for and whether improvements need to be made.

6. *Centralized Architecture and Active Monitoring:* My studies with Kermit showed that the architecture of any system visualizing the digital footprint is important. The centralized architecture for displaying the digital footprint using data collected from the router proved to be robust and easy to deploy. Installing Kermit

was much easier than installing a separate monitoring application on each client device in the home as I had done in my empirical work described in Chapter 4.

Because Kermit visualized the digital footprint using data from the router, information on all devices connected to the network, including non-computers (Xboxes, iPhones etc.) was readily available for display. Moreover, ensuring each user viewed a consistent display of the data was easier because the information was harvested from a central point on the network. In terms of the active monitoring of the digital footprint, from the Kermit study, it quickly became clear that vast amounts of data may be generated by traffic from even a few active devices on a network, depending on what is being logged. Moreover, my study confirmed that passive home network measurements need to be as unobtrusive as possible. If not, the benefits of having the tool may outweigh the annoyance of having network disruptions when speed tests are run.

In all, the Kermit study suggested that increased visibility of infrastructure could help users better manage their networked infrastructure. Next, I discuss considerations for achieving increased visibility in networked infrastructure.

6.2 Towards Inspectable Infrastructure

Several HCI researchers have suggested that systems could be both intelligible and accountable to facilitate a better overall user experience. Bellotti and Edwards [5], for example, argue that context aware systems or systems that sense information about the world around them, be intelligible in that they should "represent to their users what they know, how they know it, and what they are doing about it".

Similarly, Dourish and Button [25,27] discuss how systems that tend to black-box actions could instead allow users to see more of what happens behind the system abstraction. Doing so often helps the user understand system actions better, especially when metaphors are used in abstractions. For example, a user may drag a file from one folder to another and only then realize that these folders are on two separate machines when the file copying time is displayed, revealing the underlying network that exists between these two icons on the desktop. They argue that improved accountability in system design, or showing users what the system is doing and why, can improve users' mental models of how a system works.

These previous works focused on single systems rather than a set of systems or infrastructure, yet their notions of opening up a system to make it more accountable to users applies to infrastructure. As Star first noted [91], infrastructure has a tendency to disappear into the background and become visible when it breaks, not by design but because of the nature of the tasks that it is designed to support. I contend that previous work on making systems accountable could be extended to include a third concept related to making networked infrastructure systems more accountable through increased visibility.

In essence, my research with home networks demonstrates there is a time and place for infrastructures to be opened up and made to be what I call *inspectable*. Inspectability can arguably help facilitate intelligibility and my research has merely scratched the surface of what it means to design inspectable infrastructure and the impact of this increased visibility. In my studies, making the home network inspectable allowed users who did not understand technical terms to begin to grasp these concepts. Moreover, making the home network inspectable allowed users to feel more in control of their broadband connections. As such, inspectable infrastructures can make complex systems that require the fine orchestration of multiple devices easier for users to manage.

6.2.1 Defining Inspectability

I define ***inspectability*** as the property of a system which allows it to be explored upon desire by the user, but in a manner which is easy to understand and interpret at a level that most users can grasp. The key is that information must be presented in terms that do not require a detailed knowledge of technical concepts (e.g., bandwidth) to understand. However, the information should still be presented in a way that can facilitate learning about domain concepts and forming a conceptual model of how a system works.

The goal of making infrastructure inspectable is therefore to help users learn enough about an infrastructure to take actions to change system performance or their own behaviors. For instance, learning about how an infrastructure is being used allows the user to take a particular action to change system performance (e.g., make a connection faster), alter their own or others' behaviors (e.g., asking someone to stop a download while another person is busy on a voice call) or learn more about patterns of use for potential optimization (e.g., using the Internet at times when it is less congested). Essentially, inspectability facilitates users' developing mental models of how systems work and learning about important domain concepts. These effects can help with overall system use, maintenance, and troubleshooting.

From a technical standpoint, an inspectable infrastructure should provide information about how the infrastructure is being used in real-time, as well as information on any of the systems or devices comprising the infrastructure. Inspectable systems should also provide access to historical information about the system use over time. In other words, an inspectable infrastructure should always be collecting usage information and running either as an ambient display or application or icon in the background but be available to the user, should the user desire to look more closely at their usage habits. By receding into the background, an inspectable infrastructure maintains the black-box nature of the infrastructure and frees the user to continue with their daily tasks but provides supplemental information when it is required.

These aspects of inspectability are important for the following reasons. First, real-time usage allows users to more easily correlate their actions in the world to how and why the infrastructure is performing a certain way. For instance, seeing that one machine is hogging bandwidth may allow a user to stop streaming media on that machine to minimize disruptions to another user in the home. Second, historical information is necessary for a user to build up a mental model of how an infrastructure is used over time. As an example, a user might notice that the network always slows down in the evening at 7pm. He or she could then plan activities that require a fast connection (e.g., video streaming) to occur later in the evening. Third, subsystem information allows the user to have a central repository of data on all the systems making up a particular infrastructure. For example, in the home network, a user might more easily be able to see which devices are part of the network, how they are configured and what each device is doing on the home network. Based on my research on home networking, I outline properties of inspectability that I have derived. By outlining these properties, I provide the framework for future work on creating inspectable infrastructures. Inspectability may not apply to any infrastructure but suits itself well to networked infrastructures with multiple users sharing a resource, where making the infrastructure visible would help users to learn more about how the system works and to alter their behaviors around the system. For example, inspectability may apply to home networks, work networks, electrical and water infrastructures—all of which have multiple users sharing resources such as bandwidth, electricity and water.

I believe inspectability would only be necessary on demand since by design, infrastructure is meant to invisibly support tasks. At those points when unusual events occur or when users are curious about how infrastructure is being used, interfaces that allow inspectability are key. In other words, I foresee that interfaces to support inspectability will not be in use all the time, but only at those points in times when users need to understand more about how the infrastructure is being used. Understanding usage at these points could help users reflect on themselves, e.g., to determine if they are on Facebook too much. Usage information could also help users troubleshoot and maintain their technologies. For example, high spikes in traffic on an unused machine in the network may indicate it has a virus.

Inspectability is not just a technical issue. By its very nature inspectability reveals data flowing through infrastructure, and it is embedded within the social ecosystem of which the infrastructure is part. Recall that infrastructure mediates between different groups of users who utilize it for their needs. In the home, these users may be parents and children, husbands and wives or even ISPs and broadband users. Thus, there are politics inherent in inspectable infrastructures, and there are many factors to consider in order to be sensitive to the various users that depend on these systems.

In my own research, particularly with the Kermit study, participants varied in how much data they wanted to be shared and available to others within their household, and with visitors to their homes such as guests and technicians. Parents differed in how much they wanted to know about or control their children's Internet usage. Similarly, some couples did not want to pry into each others' usage and in households with roommates, again privacy issues surfaced around how much information should be divulged through Kermit.

Achieving inspectability is thus not without tradeoffs, particularly because making information visible has indirect consequences for those whose information is revealed, especially when that information is revealed to others, or in my case study, to others in the home. I identified six aspects of implementing inspectability that affect the social relations of those using the system:

1. Data representation

2. Data collection

3. Data access

4. Data control

5. Data storage

6. Data sharing

I discuss each of these points in turn.

6.2.1.1 Data representation

Making systems inspectable involves first determining what representation of the inner workings of the system is appropriate for users. Questions to ask at this point are:

1. At what level of granularity should we provide detail?

2. How do we make that information accessible without requiring users to know complex technological jargon and terminology?

In my studies, users liked the visualization of data in real-time so that they could more easily correlate their actions with the information on the screen. Once an appropriate representation has been designed, an inspectable system should strive for accountability. The design has to be accountable in that it should make clear what information is being collected, as well as who has access to this information. In fact, in the home, parents may choose to restrict their children's access to certain types of information being collected. In Kermit, there was no authorization or login required to view information but because of the different access to information required, access control in an inspectable system should be tailored to user needs.

In an inspectable representation, users should also be provided with options for personalization. Such personalization could allow users to streamline a representation in ways that make the data more meaningful to them. In my Kermit study, users enjoyed being able to associate pictures with their devices and the ability to quickly rename machines. This simple personalization mechanism made the home network visualization much more meaningful to participants, who used it to joke with each other and to express themselves.

6.2.1.2 Data collection

My research revealed that deciding *what* data should be collected and *how* and *when* data should be collected is important to the users whose data is being harvested. For example, in the home network, collecting more data may mean collecting URLs, times of access and duration of access as well as bandwidth information. For my participants, because Kermit did not collect this data, they were comfortable with what the display showed to others. Yet in another research project I evaluated a system called HomeWatcher [14], even showing machines' bandwidth usage information revealed quite a lot about whether household members were present in the home or engaged in play or homework activities. In a similar system with making printing jobs visible [73], printing habits can reveal which documents one is reading, which trips one is taking, doctors' appointments and so forth. Thus, at first glance, the data may seem innocuous but upon closer inspection even times of Internet usage can be incriminating. Therefore, simply not collecting obviously privacy-violating data such as URLs is not the only consideration for making a system inspectable in a manner that does not upset users whose data is involved.

Moreover, in designing an inspectable system we cannot assume that any data is benign, particularly when individuals can be identified from data usage patterns. For example, in Household 7 in my final study, a set of parents knew that Kermit had not collected all the data on one particular day. They knew their son had been up gaming past midnight, but the history graphs failed to show this information. This instance not only reveals the difficulty of achieving robust field deployments but that times of access alone can be incriminating, particular when household members or the parties involved have a power differential in their social roles. This fact rings true whether the inspectable system is in the home or in the workplace.

Having the option to opt out of contributing one's data or change how much data one is willing to contribute may help mitigate the discomfort that users of inspectable systems may feel. However, allowing opt-outs would make inspectable systems less useful if not enough users contribute their data. In smaller infrastructure systems, where users can be identified by their usage patterns, this is more of an issue. For example, in a household of two people there is less plausible deniability and disambiguating data to pinpoint who is doing what is much easier than in a family of four using shared machines. This has implications for designing an inspectable system because we as designers should provide an option to tailor what is collected, even if that compromises and weakens the utility of the data set generated.

Related to *what* data to collect is the question of *how* to collect the data. For inspectable systems, data could be mined from routers as in my case study, computers and all other technologies that users are interacting with. Again, users should be made fully aware of what and how their data is being harvested, so that they can make an informed decision about whether they want to participate or not. In my study with Kermit, I did not allow household members to opt out because data was being collected from a central point. For my study, I had to take care to explain to participants exactly what data was being collected and how I was collecting that data well before I installed Kermit. One couple had several back-and-forth conversations with me over email, so that the boyfriend could make sure that no private data was being exposed. Only by reassuring participants with screenshots and the consent form could I get my participants to feel comfortable with the study. Again, this demonstrates how sensitive users can be to inspectability. However, once the system was running, participants forgot that it was collecting data as it became another background process.

Not only was the question of *what* and *how* data would be collected important, but another question that arose for Kermit was *when* the data was collected. Participants wanted a history of bandwidth and speed usage over time and for periods of time in the order of weeks, months and years as opposed to one day. They also really liked the real-time updates of the "Who's Online" view. Therefore, for inspectable systems, choosing *when* to collect and display the data is also important. The more points collected, the more revealing data can be and the more processing power and storage capacity needed on the back-end of an inspectable system. Data points may also just confirm what household members already know about each other. For example, seeing a machine is online on Kermit and that it has traffic flowing on it, could be comforting to a parent who then knows their child is in the room using the Internet [14].

For inspectable systems, my results suggest therefore that as long as users are well informed about *what* data is being collected and *how* and *when* this data is collected as well as *who* will see this data then these systems will be more likely to be adopted. I discuss more about considering *who* will see the data in inspectable infrastructure next.

6.2.1.3 Data access

The Kermit study revealed that inspectable systems make users accountable for their actions that were previously invisible. In order words, users care about *who* can see the data that is being collected. For example, participants could now see when others in the home were online and how much bandwidth they were using. For many users, in the Kermit display, this was fairly innocuous. Yet, when asked if participants would be comfortable sharing more information with their fellow housemates, many were not comfortable with that prospect.

Kermit was designed to be viewed and accessed by anyone in the home and for many parents in particular, this was not ideal. Many parents wanted the data to only be available for their view, feeling their children did not need to know the information since they do not pay the bills. Similarly, in households with roommates, some were self-conscious about letting others know when they are online and whether they are using more of a shared resource such as bandwidth. Thus, another important factor in the design of inspectable systems is around *who* has access to the data and *who* can view the data. Particularly in the case where users have a power differential, e.g., parents and children in the home or the bill-payer versus others, making it known who can view the data and use it requires careful thought and consideration for designing an inspectable infrastructure.

6.2.1.4 Data control

For inspectable systems, representation is important but by itself it is not sufficient. In my studies, users learned more about home networking from the displayed information alone, for example, one participant learned that uploads caused network slowdowns more significantly than downloads. However, to make the system useful and to continue to engage users, an inspectable display will allow users to control some aspect of infrastructure directly from the representation.

In the Kermit study, this meant giving users control over whether a machine's traffic could be limited or prioritized. Because of the controls, users in the study were more excited at the prospects of controlling their broadband connection instead of only seeing usage information. In the Kermit study, users also wanted to see a perceptible effect after applying a control. Therefore, for inspectable infrastructures, users may reap greater benefits by seeing how the system is being used if they can also exert control over that infrastructure. In providing control, inspectable systems should also ensure there are perceptible effects of using a control.

Another important aspect of control in an inspectable system relates to *who* has control over the infrastructure. In my study with Kermit, participants took issue with the fact that anyone with access to the Kermit URL could limit or prioritize any other person on the network. For them, the open controls did not map onto current rules in the home. Participating parents felt that a user name and password should protect the system from abuse by warring siblings or that the system should cater to the household members who pay the bills and run the home. A husband in a married couple in Household 2 in the Kermit study was particularly distressed that his wife could limit and prioritize his machine. He felt that there should be a notion of hierarchy in the system and that the administrator should have more control than others. Interestingly, he did not mind as much about who saw the data but only who controlled the actions affecting network access. Others made use of the ability to rename any machine and alter computer photos to engage and play with other members in the home. In the same Household 2, the husband and wife changed their pictures, status messages and computer names as a way to joke around with each other.

In my study, households desired that their technological controls follow their existing social rules. Wyche et al. [103] found that their Kenyan participants were more apt to use social mechanisms to control content entering their homes and contrasted this to American households which are not opposed to using technology to track what content household or church members are accessing. My data suggests that while American homes rely on technology for controlling user behaviors, such as ensuring children are not exposed to inappropriate content on the Internet or to manage their time online, they still want those controls to follow social rules. In other words, the technology should take into account that those who are in control of certain aspects of running the household, including managing the infrastructure are the ones who desire priority in terms of what they control. Otherwise, the technology could create conflict and social difficulties. Providing options for implementing control to closely mimic social norms in the household is one way to mitigate this design concern.

Thus, for inspectability, the question of implementing control is coupled with *who* in the inspectable system should be able to exercise that control. Should there be a single administrator? Should access control mimic permission-granting in social situations of loaning and borrowing, as found by Mazurek et al. [59]? Open questions remain and in the home these questions revolved around who controls the bandwidth—e.g., parents, children, the network administrator or the bill-payer? (In fact, in the home, revealing the infrastructure essentially created new ideas of what can be controlled in general. For example, in my study, prior to installing Kermit, households did not realize they could so easily control access to the Internet or share their bandwidth amongst their devices and users.)

6.2.1.5 Data storage

In my final study, my participants felt safer knowing that the data collected was on a laptop in their homes. Had I designed Kermit to store the data on a central server outside the home, the question of securing the data would have been even more important because an external repository exposes the data to access by parties outside the home. Therefore, in an inspectable system, moving data storage out into the cloud brings up more privacy and security questions. For example, how can one assure that the data collected to power an inspectable system is secured and only accessible by the system or users who are allowed such permissions?

6.2.1.6 Data sharing

My participants often embraced the idea of Kermit as a consumer empowerment tool. Many wanted the ability to share the data collected with their service provider to help them troubleshoot faulty connections and ensure they were getting the service they were paying for. Others raised the idea of seeing how neighborhood speeds varied, again to help them identify the source of slowdowns as well as to find out more about variability in service delivery. To truly empower users with an inspectable infrastructure, provision has to be made to allow for multiple scales of data sharing.

In the home network case study, sharing could occur between household members in a home, but the data could also be shared with a central database to allow aggregates of information over locales, neighborhoods and cities.

These kinds of data sets not only empower individual users to find out more about their service in comparison to others but they simultaneously allow policy-makers and legislators to learn more about infrastructure performance in different areas and by various providers. Take for example, the data set of ISP performance around the U.S. recently released by the FCC, the national broadband map [31]. This tool merely maps ISP speed variations around the U.S., but using the tool, consumers can find out about speed variances and provider options in their neighborhoods. Thus both individuals and larger groups and organizations could leverage the data to be better informed. This example is similar to cell phone coverage maps.

At this level, inspectability again raises questions about how much and what should be shared as well as how to protect individual identities and privacy. In larger systems, aggregating data might be one way to mitigate data privacy issues, so that individuals or households can not be identified by their usage patterns or location if geo-spatial data is also collected. Open questions for inspectable systems that operate at this scale are how to aggregate the data to create meaningful representations for comparative purposes and preserve privacy.

To sum up, creating an inspectable system requires sensitivity to users that will use these infrastructures. With careful consideration of the properties I outlined, an inspectable design could ensure that the social relationships of users that use an inspectable system are upheld and enhanced by inspectability. Future work could investigate whether to design for inspectability from the ground up or whether inspectable interfaces can be tacked onto complex infrastructure systems after the fact. Another open question for investigation is to fully assess the benefits of inspectability and to determine when users require inspectability. These questions are left for further exploration.

6.2.2 Privacy, Surveillance and Inspectability

In the previous section, I proposed that inspectable infrastructure can help users manage and understand their everyday systems. However, I also raised a number of privacy-related issues such as users not necessarily wanting to disclose their usage habits to others. In particular, the question of whether increased surveillance, monitoring and visibility in networked infrastructure will be a positive direction for social relationships remains unanswered.

As networked technologies have taken hold in and become part of everyday life, the Human Computer Interaction (HCI) community has continued to debate about how these technologies affect privacy and social relationships. For example, Palen and Dourish [66] outline how the characteristics of networked technologies create situations where privacy may be compromised. According to these researchers, privacy management is about the continual management of boundaries between different places where interactions occur as well as the degrees of disclosure within those places. They outline several boundaries that are challenged by the ability of technologies to disrupt these boundaries, e.g., by connecting people over long distances, making communications non-ephemeral and changing with whom, what and how often data is shared.

They outline three aspects of privacy. First, they define the disclosure boundary between privacy and publicity, referring to what a user decides to disclose to maintain their privacy, as well as their public face. For example, a faculty member might keep a public web page with a CV, schedule and instructions for requesting recommendation letters to increase their visibility within their communities. At the same time, these actions serve to maintain privacy by limiting accessibility and decreasing the number of requests for meetings, copies of papers and recommendation letters.

Second, the authors define the identity boundary between the self and other, which refers to the process of identity management and controlling how others perceive us. Examples include a user choosing to publicly share a list of music that one likes via Pandora to express more about herself and her affiliation with indie music instead of mainstream music. Sometimes however, users do not make conscious decisions to share information. Instead, as Palen and Dourish remind us, many of the disclosures we make online are not under our control. For instance, merely being a member of a particular email list can disclose information about ourselves, for example revealing we belong to a running group or cooking club.

Finally, Palen and Dourish define the temporal boundaries between past, present and future which technologies disrupt by making information persistent. As an example, when applying for a job, one may not want information that one posted as an activist high school student to be available for prospective employers to see. Yet oftentimes, there is no way to remove this information if it is hosted on a site not under our control.

Clearly, inspectable interfaces affect all three of these boundaries of disclosure, particularly since the usage information collected and displayed is not under the users' direct control. For instance, usage information can affect boundaries between the self and others, as others who use an infrastructure can see another users' data. Inspectable interfaces can also break down the boundary between private and public faces if not implemented in a sensitive manner. This breakdown could be very evident in the home, when family members may not want to disclose to each other exactly when or for how long they are online—for example a spouse may not wish her husband to know she is shopping for a gift for him or parents may not want their children to know they are watching x-rated content.

Other researchers also discuss further aspects of privacy. Aoki and Woodruff [3] describe how pervasive communications technologies can often create situations where it is more difficult to perform face-work. Face-work, a term developed by Goffman [38,39] is the process of managing impressions that others have of us. This face-work may involve actions to save face, avoid embarrassment and maintain social harmony. To explain this concept, imagine the following scenario: Mary makes a call to Bob but the call is not answered. A week later Mary runs into Bob at a party. Bob may preemptively apologize for not returning Mary's call and explain that he was out of town that week. Mary can accept this response, based on previous interactions with Bob and not feel rebuked. Mary and Bob's interaction is an example of face-work between two people. Ambiguity in this case serves as a resource for maintaining the relationship since Mary does not know if Bob is telling a "white lie" or being truthful, but the net result is that the situation is diffused, preserving social harmony.

With networked technologies, Aoki and Woodruff argue that designers could be more cognizant of the fact that ambiguity in communication is sometimes desirable. Therefore communications in which some messages are dropped, lost or misrepresented can help users resolve social difficulties in everyday life and provide plausible deniability for certain social situations. The privacy debates extend to other areas of information sharing as well and the lines of user comfort zones are not always clear cut. Consider location information, for example, Brush et al. [13] have discussed how disclosing location information to others can be distressing. By contrast, Sellen et al. [83] find that sharing location information with close personal ties can be reassuring and a form of reaching out to loved ones as "social touch". Aside from the HCI communities forays into defining how to manage user privacy in an increasing world of surveillance technologies, the mainstream consumer has also been exposed to these debates, sometimes unwittingly.

For instance, in recent years in the public media, consumers have criticized social networking sites such as Facebook for their continual encroachment on individual privacy. Ironically, when Facebook first introduced the "News Feed" feature, users were outraged that their activities on the site were being made public [7, 100]. Yet soon after this feature was introduced, the site's popularity climbed even higher because seeing other users' activity on the site turned out to be a drawcard that few could resist. Other sites unabashedly embrace the idea of sharing activity data—for example, on Swipely.com users can share a history of all their credit card purchases for others to see, and on GarminConnect, users can share GPS data such as runs logged from sports watches. These sites attest to human desire to share information with others and to see what others are doing, despite the privacy implications. They also demonstrate that privacy boundaries are not always clear.

Creating inspectable infrastructures walks the line among privacy violating technologies. Much like the technologies discussed by Palen and Dourish, and Aoki and Woodruff, making infrastructure inspectable does not just affect the privacy of one individual but rather of any individuals using a particular infrastructure. Essentially, inspectability means divulging potentially personally identifiable information to anyone utilizing a particular infrastructure, often indirectly through usage measures. For example, in the home network case study, knowing a user's times online may tell you more about how often and how long they use the computer. For a child, this may mean parents could restrict what they consider excessive Internet usage habits. For husbands and wives, this may mean knowing that a spouse is online at odd hours of the night, causing suspicion about extra-marital affairs or illicit activities such as gambling or pornography. Moreover, particularly in the case of the home but also more broadly, just as ambiguity is a resource for daily interaction, so is the conscious withholding of information, or "secrets". Knowing too much about our colleagues, or the behaviors of our close personal ties could cause social breakdowns if any one individual's "secrets" are unintentionally revealed, even though the data may seem harmless. For example, information on application usage in the home network could reveal that a child spends most of their time on YouTube and not on Wikipedia, despite giving his parent the impression that he is researching a school project. It might also reveal that a someone in the household is buying a surprise gift for another household member.

Therefore, it is unclear whether inspectability will further erode or strengthen social relationships of those using inspectable systems. I argue that the key to supporting and enhancing users' relationships with one another lies within the design of an inspectable system. For example, privacy issues could be mitigated by providing the user with personalization options to control what data they share, where it makes sense to do so. This type of design addition could help users better control the boundaries between self and others and their private and public faces. A default setting could be to allow the user to share everything pertinent to the inspectable display. If the user so chooses, they can opt out or change the data set being shared. In this way, the system aims to gather the most comprehensive data set by default but provides the user with the freedom to control their data sharing.

Also, allowing users to preview how their data will be represented in a system could assuage fears of disclosing too much data. Temporal boundaries could be similarly mitigated by choosing to discard the data at certain times. Data could also be aggregated in some manner to allow users to have ambiguity as a resource for face-work in their interactions with other users of inspectable systems. These types of design considerations could make users feel less like the system is encroaching on their private actions and instead place them in control of their data, should they choose to wield this control. As much as possible, designers could strive to ensure users are in control of managing their boundaries of disclosure and given a system which does not cause social difficulties that cannot be explained away by ambiguity in what is displayed or collected.

The design suggestions I made above depend on allowing individual users to determine what is shared or not shared. However, in the home, I acknowledge that the situation is not so simple. For example, the very action of choosing to share or withhold information could be telling in itself. The spouse who does not want to share data on the times they spend online or their bandwidth usage may again incur suspicion. Deciding on what data to share at a household-level versus an individual level is not necessarily the solution either. For instance, parents may require their children to share certain information by default, causing them to feel like their household is like Big Brother. The important take-away is that inspectability is complicated because not only does it make some actions visible, it renders others invisible. As users are not just individuals in a household setting but part of the social fabric of the home and entwined in family relations, designs that are solely based on the individual may also have to be rethought. For example, in other systems, designs turning on the individual are not necessarily ideal for household situations. For example, on the Amazon Kindle, a user can buy an individual magazine subscription. Sharing this subscription between multiple Kindles in one household is not possible, despite the fact that typically for a paper magazine subscription, there need only be one per household. The question of how to properly ensure inspectability fits into home life without violating individuals' and families' privacy is left for future work.

In summary, inspectability can serve to help users manage their infrastructures but the security and privacy of user data, and the effects of the availability of this information on social relationships and users' identity management is a rich area for investigation. Future research projects could study existing instances of inspectable systems and infrastructures to better understand how users navigate their boundaries of disclosure and perform facework when more data about their usage habits are publicly revealed. Future projects could also investigate how to incorporate best practices in designing inspectable infrastructure for users to maintain privacy boundaries, control access to themselves, and perform facework and other impression management practices.

6.3 Chapter Summary

Recall that my thesis focuses on answering three research questions:

- RQ1: What visibility issues around the home network emerge from studies of households' engagement with networking infrastructure and which of these are exacerbated by the lack of a transparent digital footprint?
- RQ2: How do households perceive their computing routines and the resources they use for engagement with home networking infrastructure and how much of this is visible through the digital footprint?
- RQ3: How will surfacing invisible aspects of the digital footprint cause changes in households' engagement with home networking infrastructure? Specifically, will the following user engagements change as a result of interactions with Kermit, a technology probe for surfacing aspects of the digital footprint based on findings from RQ1 and RQ2:
  - RQ3.1: Change users sense of self-efficacy with respect to the home network
  - RQ3.2: Change computing routines and the awareness of resources users use

    e.g., Through increased problem solving, increased awareness of bandwidth, time spent on computing routines or via other emergent behaviors

In this chapter, I focused the discussion around the third research question. I found that with the Kermit study, household users did enjoy having access to the digital footprint of the home. My results suggested that users were able to become familiar with and understand more about complex concepts such as bandwidth and network speed, thus improving their technical self-efficacy. Moreover, those who were not usually involved in home networking duties became more engaged with the home network. In this chapter, I have discussed the opportunities for expansions to the Kermit study. More importantly, I described how this increased visibility or access to the digital footprint in my case study can be abstracted to apply to a networked infrastructure, such as the home network. Specifically, I described how making the invisible visible or creating inspectable infrastructures can help users manage these complex systems. I described this property as inspectability and outlined factors to consider when designing inspectable infrastructure. Finally, I discussed how inspectability is tied up with privacy discussions in HCI. In my final chapter, I will summarize the overall conclusions of my thesis and set out directions for future work.

CHAPTER VII

REFLECTIONS ON MAKING INFRASTRUCTURE VISIBLE

In this chapter, I examine the body of thesis work with a reflective lens to highlight my broader contributions to HCI in examining inspectability in the home. By focusing on the question of "Why is my Internet slowing down?", it may appear that selecting bandwidth and Internet speed as topics to represent to end-users is an easy task. However, the concepts of bandwidth and Internet speed are far from straightforward as attested to by networking researchers who are characterizing home network traffic and factors affecting broadband performance [94].

In the following sections, I reflect on my dissertation work to highlight how tackling the problem of representing these complex concepts to average users required research in a variety of areas namely:

1. Enumerating User Needs and Desires
2. Determining User Actions and Exposing Relevant Controls
3. Eliciting Conceptual Models
4. Applying Visualization Techniques

My research also has implications for public policy, which I briefly outline. Most importantly, although my reflections are grounded in the example of home networking, my results and contributions may apply to creating inspectable systems for other infrastructures where there are multiple users sharing a resource. Another example very closed related to showing users what bandwidth and Internet speed they are getting is that of the energy infrastructure in the home. As with networking, visualizing energy use in terms of electricity consumption per device, usage in real-time and historically can help households better manage their energy consumption. Inspectability therefore can apply beyond the home network to other types of technological infrastructures where there are multiple users sharing resources. Clearly, limitations exist in situations where is it difficult to represent how an infrastructure is being used.

7.1 Enumerating User Needs and Desires

Using empirical techniques, I gathered information about user needs and desires around home networking. Through the process of interviews, sketches and home visits in the places where users were utilizing the technologies I was studying, I was able to distill out the main needs of my target population. Because the Internet is a technology that most users around the world use, I was also able to identify issues which may affect users globally, such as the need to more easily monitor and control network functions and resources, e.g., bandwidth and Internet speed.

To create inspectable systems, the first step of understanding what needs to be made more visible will therefore entail a phase of data gathering to identify common user needs and desires. Once these needs have been identified, designers can then create speculative sketches or prototypes of ideas for visualizing data to meet these needs. Depending on the infrastructure under study, different data gathering techniques may be appropriate. For example, in the home network, traffic usage information may be gathered to determine ground-truth patterns of use. These patterns could then be visualized and used as a probe to find out more about user perceptions of how they use the network. I used a similar technique in the studies I conducted about home computer usage, comparing what participants felt they were spending time on with what the logs showed. This kind of technique depends on getting user permission to collect this data in the first place.

Therefore, the choice of data gathering techniques is dependent on what kinds of resource usage information can be collected about a particular infrastructure, how easy it is to get that data (if at all) and whose permission is required to get that data. Ground-truth data if it is available and possible to collect, can be supplemented with user interviews and surveys. It is preferable to study users in the place where they use the infrastructure, so at the site of usage because this more closely mimics "in the wild" usage of the infrastructure. For example, conducting home visits was more informative than interviewing participants about their networks in another setting such as a laboratory because they are more easily able to recall their usage, present examples of use and illustrate problems they have when they are already in the setting being discussed.

7.2 Determining Actions and Controls

In my empirical work, I also determined how and why users want to take action with and control the network. Actions may not involve controlling the infrastructure directly whereas controls actually allow the user to effect change within an infrastructure directly. Example actions I identified for home networking included calling an ISP to fix a problem with network connectivity or complaining about Internet slowdowns resulting from a connection being throttled.

Control mechanisms included the desire to control the speed that individuals, applications and devices experience at different times for various reasons such as prioritizing work (e.g., writing a report for work) over play (e.g., watching a YouTube video for recreation) and to restrict access for certain users, applications, and devices.

Creating inspectable systems is therefore not just about surfacing information about system usage for users. Users need to also be provided with controls over their infrastructure in addition to knowing how they are utilizing a system. I used interviews and surveys to identify what actions and controls users require of an inspectable system along with sketches. These data sources could be complemented by showing participants usage traces of how they currently use their infrastructure to elicit information about what could be improved.

In all, determining what control and actions users wish to perform with a system is a key step in making an infrastructure inspectable. By knowing the actions users need to take, we as designers can expose the relevant controls for the infrastructure and show enough information that actions can be appropriately taken.

7.3 Eliciting Conceptual Models

Bandwidth and Internet speeds, the two aspects of Internet slowdowns that I chose to focus Kermit on, are complex concepts. To probe users' mental models of these concepts, I used sketching as a research tool (a known technique for eliciting user reflective feedback [96]), throughout my research. I used sketches of the current layout of home networking infrastructure to get a sense of users' current perceptions of their home networks. I also used sketching to allow users to speculate on future broadband tool designs. Eliciting users' mental models was a key component in determining how to best represent the home network and the kinds of personalizations required for Kermit.

Sketching is therefore a valuable tool for understanding users needs and desires as well as their conceptual models of existing infrastructure. The caveat is that in situations where it is difficult to capture users' conceptual models, sketches may not be appropriate unless the sketching exercise task is very clear cut to the users or the system they are asked to sketch is not overly complex. For example, in one of my networking studies, I piloted a question to ask users to sketch out their mental model of the electricity infrastructure. The participants I tried this exercise with were unable to complete the exercise and I realized the task was too overwhelming. Yet sketching out home networks, which have artifacts that are more readily called to mind was within most participants' comfort levels for sketching. Where sketches may not be appropriate, another technique to elicit conceptual models might be to show users photos of the subject under question and to ask them to tell the researcher whatever comes to mind. Poole et al. used this technique to elicit users' notions of RFID technologies, for instance [70].

Sketches can be used in multiple parts of the design process, for eliciting users mental models and speculations on how they may like to see information represented. A thorough analysis of the sketches must occur in conjunction with other data sources to yield meaningful insights for creating an inspectable system. Sketches can be coded in a systematic manner in the same way as other qualitative data to yield interesting themes [86].

For developing inspectable systems, understanding users' conceptual models of a system is crucial for designing an interface that matches or enhances that conceptual model. As designers, we also need to be cognizant of perpetuating incorrect conceptual models through how we design our inspectable interfaces. For instance, in the Kermit system, one parent had the incorrect model of speed, thinking that slowing down their child's Internet connection would limit their time on Facebook.

This model of speed and throttling a user was not quite correct. In the case of Kermit, showing users how much bandwidth each person was consuming and allowing caps for different users on a particular day may have better solved the problem of trying to curb children's access. Thus, care needs to be taken in how system usage and controls are made visible to users.

It may not be necessary to have a one-to-one mapping between system functions and the model used for the user (e.g., the desktop metaphor and how files are stored in the file system). Instead, we need to carefully craft conceptual models that allow users to best make sense of their infrastructural systems and use them in ways that they desire.

Most importantly, when exposing functionality to a user, it is not necessary to break the black-box model of software to show them exactly what a system is doing. Rather, by focusing on how a system is being used and how to change that usage, users can more easily control that infrastructure. In all, eliciting conceptual models, which has formed a key part of my work, is essential in developing other types of inspectable systems.

7.4 Applying Visualization Techniques

To achieve inspectability, creative visualization techniques can show home network users data in user friendly terms. While there are many possible and often complicated visualizations of the network traffic flows that can be shown to users, e.g., displaying every traffic flow between every machine on a home network, users may not need to see these details.

Instead, users need the network functionality to be exposed in ways that are intuitive and which make it easier to monitor and control the network. In this case, standard information visualization techniques created for large scale data sets are not necessary ideal because they focus on visualizing large data sets, and on expert users.

In the home environment by contrast, there may a more limited set of devices and users. Even when there are many users of a system, the visualizations do not necessarily need to allow users to investigate their data sets in the same way that an info viz technique is geared towards. For example, a tree-map visualization may not necessarily be appropriate for exploring bandwidth usage over a month. However, it may be useful for those keenly interested users who want to see the portion of traffic going through different ports.

For both novice and experts users, we as designers of inspectable systems, should strive to show as much information as necessary that allows users to see what is occurring in an infrastructure so that action can be taken or an infrastructure control can be applied. Therefore to represent bandwidth as a household commodity, casual info viz [72] techniques which are not focused solely on expert users may be more appropriate than typical information visualization representations.

In the case of Kermit, a user may only need to know at a high level where the source of a potential Internet slow-down is to decide whether to call their ISP to fix a problem or whether the problem lies with a particular device. Similarly, with regard to exposing controls, the visualization techniques we select are depend on developing appropriate conceptual models for users to take appropriate actions and control their infrastructure.

In the case of home networking, the most relevant representations for networking concepts for novice and expert uses alike are still open for investigation. Because network resources are so complicated and constantly varying, developing appropriate mental models for users and creating the respective interfaces to the networking functionality is a research area unto itself. For control mechanisms simplifying and hiding complexity in the home network is key for bringing that functionality to the average end-user.

I designed Kermit to make network controls easier—for example, the process of setting a rule on the router to change the way a particular machine's traffic was treated, was simplified to a "prioritize" or "limit" a device. Inspectability therefore requires creative visualization techniques for showing usage, for exposing controls, and for allowing users to form the correct conceptual model required to manage and control the network. Inspectable visualizations have the potential to make contributions in the casual info viz space in particular. Again, depending on the infrastructure, different visualizations may be applicable and in some cases, it may not make sense to visualize usage, either because of technical difficulties or social norms. For instance, visualizing toilet usage in great detail may not appeal to all users even though it reveals a contributing cause of water usage within the home. An alternative technique to visualization is to create tangible interfaces that fit in with a user's conceptual model of system usage. For example, to restrict bandwidth usage to a device, opening a physical facet representing bandwidth may be more appropriate than a visualization alone.

7.5 Implications for Public Policy

The debate about who governs the Internet is ongoing [102]. Hotly contested topics by both consumer groups, government, and large corporations include continuing discussions about who should run Internet infrastructure and distribute Internet content as well as how much each party should pay for carrying content, or providing content. At the time of writing this dissertation, it is also still unclear about what rights consumers have with respect to broadband services, as well as whose obligation it is to provide these services in the first place, e.g., government or communities, or corporate sponsors as in the case of free WiFi networks in several cities and towns.

My research has highlighted that consumers may be uninformed with respect to Internet issues. Additionally, my research illustrates how broadband tools that make home networks more inspectable can help consumers take a more informed role in Internet debates. These tools can also help collect data sets for policy-makers who need to regulate broadband Internet services in general, whether for home or mobile users.

Creating inspectable systems is therefore entwined in public policy because broadband tools that make home Internet infrastructure more visible and manageable empowers both consumers, regulators and providers alike. Inspectable systems can inform consumers about whether they are getting the service they are paying for, and where and when problems occur.

Such systems can also help providers improve their service to their customers and verify their own measurements against independent tests because they can be held accountable for their actions. Finally, governments and regulators can benefit from data sets collected by household broadband management tools for informing public policy related to Internet issues.

7.6 Chapter Summary

In this chapter, I reflected on the many research components that my dissertation work has been comprised of with respect to the larger body of HCI research. My research has required investigation of user needs and desires, enumerating the actions and controls users need, uncovering conceptual models of complex concepts such as bandwidth and Internet speed and finding ways to visualize networking information to end-users.

Additionally, my work has implications for public policy around the Internet, a technology that is steadily pervading homes and mobile devices around the globe. All these components make for a rich research area around creating, designing, and evaluating other inspectable systems.

To sum up, we are all increasingly dependent on the Internet in our daily lives and understanding the various aspects of the puzzle to allow users to do the following is a crucial step in making the Internet more usable for all of us:

1. Stay informed about Internet issues
2. Monitor network usage
3. Take action based on information shown
4. Control network usage and resources directly
5. Contribute data to collective data sets on Internet performance

In this chapter, I have outlined the various research areas that inspectability touches upon. In the following chapter, I outline directions for future research to create inspectable systems and state my conclusions.

CHAPTER VIII

CONCLUSIONS AND FUTURE WORK

In this final chapter, I provide a summary of the overall work completed during this dissertation project. I also draw out my conclusions and make suggestions for future work.

8.1 Summary of Contributions and Conclusions

In this thesis, I have described my investigation of surfacing the invisible in infrastructure to affect how users engage with these systems. I focused specifically on the case study of the home network. I described how using empirical work, I identified problems related to the visibility of information on the home network, that is the inaccessible nature of the digital footprint of the home.

I then used a lightweight data collection and visualization tool, PersonalVibe, to determine how users respond to basic information about computer usage around power habits. Next, I used the empirical results and results from the deployment study to inform the design, and implementation of a technology probe called Kermit. With Kermit, I chose to surface aspects of the digital footprint related to why the Internet is slowing down in the home. My aim with Kermit was to gage reactions to the concept of a broadband management tool that provides near-real time usage information about the home network.

In my full field trial evaluation with Kermit, I found that users had taken issues with limitations of the probe but generally embraced the idea of seeing more information about their home's digital footprint. They also delighted in the ability to control their infrastructure more easily. From these and other insights, I discussed how making infrastructure more visible, can help users manage complex technologies.

I introduced a new concept called inspectability and outlined a framework for achieving inspectability. I also discussed the privacy implications of making infrastructures more visible. My main contributions are:

- Empirical evidence of the difficulties of setting up, maintaining and troubleshooting home networks
- Field evidence of how users respond to basic usage information such as when computer applications are used, for how long, and when
- A novel technology probe serving as a proof-of-concept for a home broadband management tool
- Field evidence of user reactions to a precursor tool for inspectable infrastructures
- Introduction of the term inspectability and a framework for designing inspectable infrastructures

Returning to the research questions, I can make the following conclusions in answering each one:

- RQ1: What visibility issues around the home network emerge from studies of households' engagement with networking infrastructure, and which of these are exacerbated by the lack of a visible digital footprint?
  - Households do experience difficulties with home networking infrastructure that is exacerbated by the lack of a visible digital footprint. For instance, not having a central management console for all devices on the network makes it difficult to plan changes to the network, determine the source of network problems and troubleshoot when something goes wrong. Therefore, making the network more visible is the next logical step to improve management and user understanding of their networks.

- RQ2: How do households perceive their computing routines and the resources they use for engagement with home networking infrastructure, and how much of this is visible through the digital footprint?
  - Households spend a lot of time managing the network and yet are not aware of the time and effort or other resources the network consumes. Even when showed basic information about their usage, household members were intrigued by the visibility of their actions. This suggests that having access to the information from the digital footprint will cause households to reflect on their use of the network.
- RQ3: How will surfacing invisible aspects of the digital footprint cause changes in households' engagement with home networking infrastructure?
  - With Kermit, users responded positively to the Kermit probe despite its limitations, appreciating the information about their network speeds and who was online. They also made suggestions for improving visual broadband tools. In all, my results from the Kermit field trial suggest there is a need to create more inspectable home networking infrastructure. Additionally, my results imply that doing so may help users manage their networks according to their needs and desires.
- Specifically, will the following user engagements change as a result of interactions with Kermit, a technology probe for surfacing aspects of the digital footprint based on findings from RQ1 and RQ2:
  - RQ3.1: Change users sense of self-efficacy with respect to the home network
    * Users that were not initially engaged with home networking in their homes and who did not know much about the technical details of

their home networks, became more comfortable with complex concepts such as bandwidth and network speed. Moreover, particularly for users that did not engage with the home network prior to the Kermit deployment, they spoke more confidently of using network tools to control limits and priorities and set rules for access. This result suggests that inspectability could help increase users sense of self-efficacy with technology if designed properly.

- RQ3.2: Change computing routines and the awareness of resources users use

  e.g., Through increased problem solving, increased awareness of bandwidth, time spent on computing routines or via other emergent behaviors

  * My Kermit study was too short to observe any long term and lasting changes in home networking practices. However, my participants were definitely more aware of, and conscious of broadband habits after using Kermit. Those who had not previously engaged in home networking tasks took time to play with Kermit, even outside of the homework tasks assigned. I see this as a positive indication that designing simple inspectable interfaces for the average user, with sophisticated options for advanced users will help users manage their home networks more effectively.

Next, I describe directions for future work in this area.

8.2 Architecting Inspectable Home Network Infrastructure

Patel et al. [67] defined infrastructure mediated sensing as using the existing infrastructure in a home to sense events about home occupants. I propose that a sub-area of this kind of sensing could be devoted to using data from the digital footprint to detect and classify user activities and locations from network traffic data alone. My research with PersonalVibe (described in Chapter 4), Kermit (described in Chapter 5) and HomeWatcher (described in [14]) has provided insights into how such a sensing tool could be constructed for what I will call ***network-mediated sensing***. Next, I discuss some directions for future research to realize network-mediated sensing, which would form the basis of and power interfaces for an inspectable home network specifically.

8.2.1 Considerations for Network-Mediated Sensing

The best way to architect a robust and more complete centralized network-mediated system for the home network remains an open question. There are many issues which require further research, and I enumerate only a few:

8.2.1.1 How should one create a centralized architecture for network-mediated sensing?

My experience with the instruments in my studies lead me to believe that networked mediated sensing in the home will benefit from a centralized architecture as opposed to a client-server architecture. By centralized, I mean having one central point on the network where one collects network information on the digital footprint from, such as the router as with Kermit. By client-server architecture, I mean installing a client agent on each device in the home network to collect network information about that device and having each client agent send their data to a central server on the network or outside the home. PersonalVibe used a client architecture without a central server. In other research outside the scope of this dissertation, I worked on HomeWatcher, which had a pure client-server architecture.

There are many arguments against installing an agent on each device. First, installing data collection agents on each machine or device in the home means longer installation times. For the study described in Chapter 4, installing our software took up to two hours on older machines. Second, the agent software has to be compatible with multiple operating systems. For instance, PersonalVibe only ran on Windows machines, and even then only on certain versions, meaning I could not recruit users with non-Windows machines into the study. Third, when there are multiple data collection points, there are larger difficulties in creating an integrated view of the data from these various sources, as opposed to having a single central viewpoint.

For these reasons, I believe a centralized architecture for network-mediated sensing is the better route to take to power an inspectable home network. Future research can determine exactly how to best construct this centralized architecture, as Kermit served only as a proof-of-concept technology and research instrument.

8.2.1.2 Which data points are of interest to end-users?

Future research could determine which data points in the digital footprint are most useful to end-users. In this way, the back-end of a fully fledged networked mediated sensing system could concentrate on collecting only the measures that are most pertinent to an inspectable infrastructure. In my work, I chose only a small subset of the digital footprint to visualize, yet there are many other aspects of the footprint to which users may desire access. For instance, with continued net neutrality debates and the threat of a tiered Internet service, users need to know now more than ever what level of services they are getting from their providers. This is not just in terms of network speed but also in terms of whether the ISPs are keeping to their terms of agreement.

In addition, recently there have been moves in the U.S. to introduce data caps on broadband connections such as AT&T's decision to implement 150 GB caps for DSL subscribers and 250 GB caps for U-Verse subscribers. How users orient to data caps and what information to surface to help them better manage these constraints will become an increasingly important area of research. I have already begun research in this latter area in South Africa where the data caps are much lower and more common [19], but U.S. based initiatives will be valuable as well.

8.2.1.3 When is the data no longer useful?

Further research could also investigate where there are points at which the data being collected is no longer useful. Answering this question has implications for how much storage is needed to power an inspectable infrastructure and for how much space a networked mediated sensing system needs to allocate for users. Furthermore, answering this question would be helpful for understanding what types of history views are useful to users and why. For example, users may require a historical timeline for troubleshooting problems or to determine their average usage over several months.

8.2.1.4 When and can the data be aggregated to make it more meaningful to users?

Understanding how to aggregate data collected by a networked mediated sensing system is important for preserving the privacy of users of an inspectable infrastructure. Aggregates can make the data more meaningful and potentially mean that individual users can not be singled out, thus maintaining social harmony in the home. Aggregating the data again has implications for data storage.

8.2.1.5 What is the best way to store the data?

In the Kermit system, I ran the data collection software on a laptop and stored the data on a server laptop in the home. A better implementation of a networked mediated sensing system might be to store the data in the cloud, taking care to minimize the security risks of having personal data stored outside of the home.

8.2.1.6 Can the data be used to classify user activities and locations within the home?

A network-mediated sensing system would create a powerful inspectable infrastructure if it could also automatically detect and classify user activities in the home. For instance, one could envision using the digital footprint to determine whether someone is watching a video or making a voice call. Another example of classification might be using the digital footprint and sensed data to determine that someone is in the living room versus an office. These types of information classification would help to optimize an infrastructure and could again be used to display to an inspectable interface. A user might want to know for example when there is unauthorized access in their homes, by seeing when non-vetted network traffic occurs.

8.2.1.7 How can users be given more accurate information and control over their broadband connection?

In a network-mediated sensing system, the speed tests could be improved. My Kermit speed tests were limited in that they could have been subject to the effects of traffic-optimization techniques employed by ISPs such as providing an initial higher throughput of traffic for downloads. Moreover, the traffic rules I set on the router for prioritization and limiting alone may not have been sufficient to have the desired effect. Future projects could therefore optimize and improve the network measurements that are collected, as well as how the controls are effected at the network-level. These low-level improvements will enhance an inspectable system, by making a back-end more responsive to user requests and improving the accuracy of the data to be reported to end-users.

8.2.1.8 Can the data be used to make home optimizations by using actuation sensors?

Further down the line, once research has determined what network-mediated sensing can sense from the digital footprint, I believe the next step will be to investigate how to use the information for implementing more control in an inspectable interface. For example, if network-mediated sensing can detect that nobody is home, the temperature could be adjusted, and lights could be switched off. Similarly, networking activities that are usually invasive could be conducted at these times such as backups to the cloud, which might otherwise affect network performance while users are around.

8.2.2 Limitations and Concluding Remarks

In conclusion, it has been a long journey to uncover home networking practices in American households. My dissertation work has yielded rich results, but the research is not without certain limitations. For example, the Kermit study was fairly short, and to truly study long-term changes and effects of an inspectable system, a longer term study of users living with inspectable systems would be instructive. Moreover, because I did not collect a large array of networking measurements from the first home visit in my Kermit study, it was difficult for me to assess how networking behaviors had quantitatively changed during the study period. A future question might be to determine whether users actually modified their behaviors in response to being monitored.

In addition, I focused on a specific demographic of middle-class families in the U.S. because the expense of computing equipment and Internet access can unintentionally exclude many lower-income groups from such studies. Moreover, the back-end measurements and tests for a network-mediated system back-end could be improved. Additionally, to better learn from these types of studies, we could log a more comprehensive network data set such as when different users are using devices, which devices are being used, all depending on how comfortable users feel in sharing this data.

Most importantly, I end with the thought that home networks and infrastructures in general are constantly evolving. In the home, users are always being exposed to the latest technologies that must mix in with their older systems. Broadband speeds are getting faster, whilst Internet congestion is getting worse. With increased speed comes new applications and with congestion comes more debate about how to best charge for Internet services. Thus, my research stands only as a snapshot of American home networking practices at the time of this research. However, the evolving and ever-shifting nature of technologies mean that there is reason to repeat studies of home networking often, to keep a finger on the most current issues affecting home users. Moreover, more generally as we build more complex infrastructures, inspectability can be one vehicle for improving the end-user experience with the caveat that it brings with it its own Pandora's box around privacy. Finally, the areas of inspectability and network-mediated sensing I described are ripe with open questions for future research that can build upon the work presented here.

8.3 Chapter Summary

In this chapter, I provided an overall summary of how I answered my main research questions. I also outlined my major contributions. Next, I discussed directions for future work, particularly on creating back-end systems for inspectable infrastructure which I called network-mediated sensing systems. Finally, I made concluding remarks.

APPENDIX A

SELECTED KERMIT FIELD TRIAL STUDY INSTRUMENTS

A.1 Kermit Pre-Study Survey

Name:______________________________ Date:______________________________

Thank you for participating in the Kermit Study ☺ This short survey will help us understand how comfortable you are with computers – please answer as honestly as you can.

Instructions: For each statement, read the statement and then circle the option that best describes how you feel about the statement. If you have any questions or do not understand the statement, feel free to ask the researcher to explain.

Section 1: General Technology Questions	**Strongly Disagree**		**Neutral**		**Strongly Agree**
1. I feel confident entering and saving data (words and numbers) into a file.	[1]	[2]	[3]	[4]	[5]
2. I feel confident opening up a file to view on a monitor.	[1]	[2]	[3]	[4]	[5]
3. I feel confident saving files correctly.	[1]	[2]	[3]	[4]	[5]
4. I feel confident handling a CD correctly.	[1]	[2]	[3]	[4]	[5]
5. I feel confident exiting from a program.	[1]	[2]	[3]	[4]	[5]
6. I feel confident making selections from an on-screen menu.	[1]	[2]	[3]	[4]	[5]
7. I feel confident copying an individual file.	[1]	[2]	[3]	[4]	[5]
8. I feel confident using the computer to write a letter or essay.	[1]	[2]	[3]	[4]	[5]
9. I feel confident moving the cursor around the monitor screen.	[1]	[2]	[3]	[4]	[5]
10. I feel confident working on a personal computer.	[1]	[2]	[3]	[4]	[5]
11. I feel confident using a printer to make a "hardcopy" of my work.	[1]	[2]	[3]	[4]	[5]
12. I feel confident getting rid of files when they are no longer needed.	[1]	[2]	[3]	[4]	[5]
13. I feel confident copying a disk.	[1]	[2]	[3]	[4]	[5]
14. I feel confident adding and deleting information to and from a data file.	[1]	[2]	[3]	[4]	[5]
15. I feel confident getting software up and running.	[1]	[2]	[3]	[4]	[5]
16. I feel confident organizing and managing files.	[1]	[2]	[3]	[4]	[5]
17. I feel confident understanding terms/words relating to computer software.	[1]	[2]	[3]	[4]	[5]
18. I feel confident understanding terms/words relating to computer hardware.	[1]	[2]	[3]	[4]	[5]
19. I feel confident describing the function of computer hardware (keyboard, monitor, disk drives, processing unit).	[1]	[2]	[3]	[4]	[5]
20. I feel confident troubleshooting computer problems.	[1]	[2]	[3]	[4]	[5]
21. I feel confident explaining why a program (software) will or will not run on a given computer.	[1]	[2]	[3]	[4]	[5]
22. I feel confident understanding the three stages of data processing: input, processing, output.	[1]	[2]	[3]	[4]	[5]
23. I feel confident learning to use a variety of programs (software).	[1]	[2]	[3]	[4]	[5]
24. I feel confident using the computer to analyze number data.	[1]	[2]	[3]	[4]	[5]
25. I feel confident learning advanced skills within a specific program (software).	[1]	[2]	[3]	[4]	[5]
26. I feel confident using the computer to organize information.	[1]	[2]	[3]	[4]	[5]
27. I feel confident writing simple programs for the computer.	[1]	[2]	[3]	[4]	[5]
28. I feel confident using the user's guide when help is needed.	[1]	[2]	[3]	[4]	[5]
29. I feel confident getting help for problems in the computer system.	[1]	[2]	[3]	[4]	[5]
30. I feel confident logging onto a computer system.	[1]	[2]	[3]	[4]	[5]
31. I feel confident logging off a computer system.	[1]	[2]	[3]	[4]	[5]

Section 2: General Computing Questions	Strongly Disagree		Neutral		Strongly Agree
1. I feel insecure about my ability to interpret a computer printout	[1]	[2]	[3]	[4]	[5]
2. I look forward to using a computer on my job	[1]	[2]	[3]	[4]	[5]
3. I do not think I would be able to learn a computer programming language	[1]	[2]	[3]	[4]	[5]
4. The challenge of learning about computers is exciting	[1]	[2]	[3]	[4]	[5]
5. I am confident that I can learn computer skills	[1]	[2]	[3]	[4]	[5]
6. Anyone can learn to use a computer if they are patient and motivated	[1]	[2]	[3]	[4]	[5]
7. Learning to operate computers is like learning any new skill, the more you practice, the better you become	[1]	[2]	[3]	[4]	[5]
8. I am afraid that if I begin to use computer more, I will become more dependent upon them and lose some of my reasoning skills	[1]	[2]	[3]	[4]	[5]
9. I am sure that with time and practice I will be as comfortable working with computers as I am working by hand	[1]	[2]	[3]	[4]	[5]
10. I feel that I will be able to keep up with the advances happening in the computer field	[1]	[2]	[3]	[4]	[5]
11. I would dislike working with machines that are smarter than I am	[1]	[2]	[3]	[4]	[5]
12. I feel apprehensive about using computers	[1]	[2]	[3]	[4]	[5]
13. I have difficulty in understanding the technical aspects of computers	[1]	[2]	[3]	[4]	[5]
14. It scares me to think that I could cause the computer to destroy a large amount of information by hitting the wrong key	[1]	[2]	[3]	[4]	[5]
15. I hesitate to use a computer for fear of making mistakes that I cannot correct	[1]	[2]	[3]	[4]	[5]
16. You have to be a genius to understand all the special keys contained on most computer terminals	[1]	[2]	[3]	[4]	[5]
17. If given the opportunity, I would like to learn more about and use computers more	[1]	[2]	[3]	[4]	[5]
18. I have avoided computers because they are unfamiliar and somewhat intimidating to me	[1]	[2]	[3]	[4]	[5]
19. I feel computers are necessary tools in both educational and work settings	[1]	[2]	[3]	[4]	[5]

Section 3: Internet Speed	Strongly Disagree		Neutral		Strongly Agree
1. I would be willing to pay a monthly internet subscription fee to access the following services:	[1]	[2]	[3]	[4]	[5]
A. Google	[1]	[2]	[3]	[4]	[5]
B. YouTube	[1]	[2]	[3]	[4]	[5]
C. Skype	[1]	[2]	[3]	[4]	[5]
D. Facebook	[1]	[2]	[3]	[4]	[5]
E. Flickr	[1]	[2]	[3]	[4]	[5]
F. Hulu	[1]	[2]	[3]	[4]	[5]
2. I would be willing to pay a fixed monthly internet subscription fee for all services included	[1]	[2]	[3]	[4]	[5]
3. I feel confident that I am receiving the service I pay for from my provider (e.g. AT&T, Comcast etc).	[1]	[2]	[3]	[4]	[5]
4. I have performed an internet speed test to test my internet speed.	[1]	[2]	[3]	[4]	[5]
5. Knowing my internet speed helps me ensure I am getting the service I am paying for	[1]	[2]	[3]	[4]	[5]
6. I have no need to know my internet speed	[1]	[2]	[3]	[4]	[5]

Section 4: Bandwidth	Strongly Disagree		Neutral		Strongly Agree
1. I am not sure what bandwidth is	[1]	[2]	[3]	[4]	[5]
2. I am not sure what speed we are supposed to be getting	[1]	[2]	[3]	[4]	[5]
3. I feel that the following factors affect the internet speed I am getting:	[1]	[2]	[3]	[4]	[5]
A. Time of day	[1]	[2]	[3]	[4]	[5]
B. My internet provider	[1]	[2]	[3]	[4]	[5]
C. My computer	[1]	[2]	[3]	[4]	[5]
D. Someone in the house hogging the bandwidth	[1]	[2]	[3]	[4]	[5]
E. I don't know	[1]	[2]	[3]	[4]	[5]
4. Sharing bandwidth in the home should be done by:	[1]	[2]	[3]	[4]	[5]
A. Person e.g. mom, dad, roommate	[1]	[2]	[3]	[4]	[5]
B. Activity e.g. work or homework	[1]	[2]	[3]	[4]	[5]
C. Time of day e.g. after work	[1]	[2]	[3]	[4]	[5]
D. Fixed everyone should get an equal share	[1]	[2]	[3]	[4]	[5]
E. One person decides the rules	[1]	[2]	[3]	[4]	[5]
F. Whoever needs it	[1]	[2]	[3]	[4]	[5]

Section 5: Privacy & Sharing/Monitoring Technologies	Strongly Disagree		Neutral		Strongly Agree
1. I am willing to share information about when I am online when I am in my house:					
A. With my family	[1]	[2]	[3]	[4]	[5]
B. With my friends	[1]	[2]	[3]	[4]	[5]
C. With my work/school colleagues	[1]	[2]	[3]	[4]	[5]
D. With everyone in this house	[1]	[2]	[3]	[4]	[5]
E. With nobody	[1]	[2]	[3]	[4]	[5]
2. I would like to send instant messages to people in the same house	[1]	[2]	[3]	[4]	[5]
3. I feel the home network should have a password	[1]	[2]	[3]	[4]	[5]
4. I prefer it if not everyone knew when and for how long I am online	[1]	[2]	[3]	[4]	[5]
5. I am not comfortable if others know what websites I am visiting	[1]	[2]	[3]	[4]	[5]
6. I do not mind if others know how much bandwidth I am using	[1]	[2]	[3]	[4]	[5]

Thank you for participating in the Kermit study ☺!

A.2 Kermit Demographic Survey

Pre-Study Survey

Thank you for participating in the Kermit study. In this survey, we would like you to answer some questions about the types of devices you own and to collect your basic demographic information. Please answer the questions as best as you can. If you have any questions, please call Marshini Chetty on 404-384-9508 or email marshini@cc.gatech.edu.

[Basic Demographics]:

Question 1: Please list all the household members in your home, their ages, occupation and relationship to you:

Person	Gender	Age	Occupation	Relationship

Question 2: What is your Total Annual Household Income (Please circle the most appropriate option):

a. Less than $20,000
b. $20,000 – $49,000
c. $50,000 - $79,000
d. $80,000 - $109,000
e. $110,000-$139,000
f. $140,000-$170,000
g. More than $170,000

[Computer Technologies]:

Question 3: In this section, we would like to learn more about the types of devices you have and how you use them. Please fill out the following table to tell us a little more about each device. Check the options that apply to your device. If you need extra pages, please ask Marshini ☺.

Device Name & Owner	Who uses it?	Type	Operating System	Location	Estimated Purchase Date	Frequency of use	Types of Applications used on this device
1.		**A.** Desktop **B.** Laptop **C.** Netbook **D.** Other, please specify: _______	**A.** Win XP **B.** Win Vista **C.** Win 7 **D.** Linux **E.** Mac OS **F.** Other, please specify: _____	**A.** Bedroom **B.** Living room **C.** Study **D.** Dining room **E.** Bathroom **F.** Kitchen **G.** Other, please specify: _____	**A.** < 6 mnths old **B.** < 1 yr old **C.** < 2 yrs old **D.** < 5 yrs old **E.** < 10 yrs old **F.** > 10 yrs old	**A.** 1-3 hrs a day **B.** <1 hr per day **C .** >3 hrs per day **D .** Only a few times a week **E .** Only a few times a month	**A**. Email **B**. Web browsing **C**. Media player for movies or music **D.** File sharing e.g. Bit Torrent etc **E**. Print from here **F**: Has printer attached to it **G**. Web server **H**. Gaming e.g. World of Warcraft etc **I**. Other, please specify: _______
2.		**A.** Desktop **B.** Laptop **C.** Netbook **D.** Other, please specify: _______	**A.** Win XP **B.** Win Vista **C.** Win 7 **D.** Linux **E.** Mac OS **F.** Other, please specify: _____	**A.** Bedroom **B.** Living room **C.** Study **D.** Dining room **E.** Bathroom **F.** Kitchen **G.** Other, please specify: _____	**A.** < 6 mnths old **B.** < 1 yr old **C.** < 2 yrs old **D.** < 5 yrs old **E.** < 10 yrs old **F.** > 10 yrs old	**A.** 1-3 hrs a day **B.** <1 hr per day **C .** >3 hrs per day **D .** Only a few times a week **E .** Only a few times a month	**A**. Email **B**. Web browsing **C**. Media player for movies or music **D.** File sharing e.g. Bit Torrent etc **E**. Print from here **F**: Has printer attached to it **G**. Web server **H**. Gaming e.g. World of Warcraft etc **I**. Other, please specify: _______
3.		**A.** Desktop **B.** Laptop **C.** Netbook **D.** Other, please specify: _______	**A.** Win XP **B.** Win Vista **C.** Win 7 **D.** Linux **E.** Mac OS **F.** Other, please specify: _____	**A.** Bedroom **B.** Living room **C.** Study **D.** Dining room **E.** Bathroom **F.** Kitchen **G.** Other, please specify: _____	**A.** < 6 mnths old **B.** < 1 yr old **C.** < 2 yrs old **D.** < 5 yrs old **E.** < 10 yrs old **F.** > 10 yrs old	**A.** 1-3 hrs a day **B.** <1 hr per day **C .** >3 hrs per day **D .** Only a few times a week **E .** Only a few times a month	**A**. Email **B**. Web browsing **C**. Media player for movies or music **D.** File sharing e.g. Bit Torrent etc **E**. Print from here **F**: Has printer attached to it **G**. Web server **H**. Gaming e.g. World of Warcraft etc **I**. Other, please specify: _______

4.		**A.** Desktop **B.** Laptop **C.** Netbook **D.** Other, please specify: _______	**A.** Win XP **B.** Win Vista **C.** Win 7 **D.** Linux **E.** Mac OS **F.** Other, please specify: _____	**A.** Bedroom **B.** Living room **C.** Study **D.** Dining room **E.** Bathroom **F.** Kitchen **G.** Other, please specify: _____	**A.** < 6 mnths old **B.** < 1 yr old **C.** < 2 yrs old **D.** < 5 yrs old **E.** < 10 yrs old **F.** > 10 yrs old	**A.** 1-3 hrs a day **B.** <1 hr per day **C .** >3 hrs per day **D .** Only a few times a week **E .** Only a few times a month	**A**. Email **B**. Web browsing **C**. Media player for movies or music **D**. File sharing e.g. Bit Torrent etc **E**. Print from here **F**: Has printer attached to it **G**. Web server **H**. Gaming e.g. World of Warcraft etc **I**. Other, please specify: _______
5.		**A.** Desktop **B.** Laptop **C.** Netbook **D.** Other, please specify: _______	**A.** Win XP **B.** Win Vista **C.** Win 7 **D.** Linux **E.** Mac OS **F.** Other, please specify: _____	**A.** Bedroom **B.** Living room **C.** Study **D.** Dining room **E.** Bathroom **F.** Kitchen **G.** Other, please specify: _____	**A.** < 6 mnths old **B.** < 1 yr old **C.** < 2 yrs old **D.** < 5 yrs old **E.** < 10 yrs old **F.** > 10 yrs old	**A.** 1-3 hrs a day **B.** <1 hr per day **C .** >3 hrs per day **D .** Only a few times a week **E .** Only a few times a month	**A**. Email **B**. Web browsing **C**. Media player for movies or music **D**. File sharing e.g. Bit Torrent etc **E**. Print from here **F**: Has printer attached to it **G**. Web server **H**. Gaming e.g. World of Warcraft etc **I**. Other, please specify: _______
6.		**A.** Desktop **B.** Laptop **C.** Netbook **D.** Other, please specify: _______	**A.** Win XP **B.** Win Vista **C.** Win 7 **D.** Linux **E.** Mac OS **F.** Other, please specify: _____	**A.** Bedroom **B.** Living room **C.** Study **D.** Dining room **E.** Bathroom **F.** Kitchen **G.** Other, please specify: _____	**A.** < 6 mnths old **B.** < 1 yr old **C.** < 2 yrs old **D.** < 5 yrs old **E.** < 10 yrs old **F.** > 10 yrs old	**A.** 1-3 hrs a day **B.** <1 hr per day **C .** >3 hrs per day **D .** Only a few times a week **E .** Only a few times a month	**A**. Email **B**. Web browsing **C**. Media player for movies or music **D**. File sharing e.g. Bit Torrent etc **E**. Print from here **F**: Has printer attached to it **G**. Web server **H**. Gaming e.g. World of Warcraft etc **I**. Other, please specify: _______

[Other Technologies]:

Question 4: In this section, we would like to learn more about the other types of devices you own. Please fill out the following table to tell us a little more about your other devices like your TVs, game consoles (xbox, playstations, etc), music players (ipods/stereos and personal mobile devices) in the table below.

	Device Type	**Device Location**	**Device Owner**	**Device Users**	**Estimated Purchase Date**
1.	A. Television B. PVR/TiVo C. Xbox D. Playstation E. Other, please specify: _____	A. Bedroom B. Living room C. Study D. Dining room E. Bathroom F. Kitchen G. Other, please specify: _____			A. < 6 mnths old B. < 1 yr old C. < 2 yrs old D. < 5 yrs old E. < 10 yrs old F. > 10 yrs old
2.	A. Television B. PVR/TiVo C. Xbox D. Playstation E. Other, please specify: _____	A. Bedroom B. Living room C. Study D. Dining room E. Bathroom F. Kitchen G. Other, please specify: _____			A. < 6 mnths old B. < 1 yr old C. < 2 yrs old D. < 5 yrs old E. < 10 yrs old F. > 10 yrs old
3.	A. Television B. PVR/TiVo C. Xbox D. Playstation E. Other, please specify: _____	A. Bedroom B. Living room C. Study D. Dining room E. Bathroom F. Kitchen G. Other, please specify: _____			A. < 6 mnths old B. < 1 yr old C. < 2 yrs old D. < 5 yrs old E. < 10 yrs old F. > 10 yrs old
4.	A. Television B. PVR/TiVo C. Xbox D. Playstation E. Other, please specify: _____	A. Bedroom B. Living room C. Study D. Dining room E. Bathroom F. Kitchen G. Other, please specify: _____			A. < 6 mnths old B. < 1 yr old C. < 2 yrs old D. < 5 yrs old E. < 10 yrs old F. > 10 yrs old

Question 5: Do you have other portable devices? Yes/No
Please specify:

Question 6: How many mp3 players/ipods are there in the house?_________________________
Are they are all in regular use? Yes/No

Question 7: How many cellphones are there in the house?________________________________
Are they are all in regular use? Yes/No
Check all the types of cell phone that apply:

A. iPhone
B. Blackberry
C. Smartphone/PDA
D. Nokia
E. Motorola
F. Siemens
G. Other, please specify: ____

[Home Network]:

Question 8: In this section, we would like to learn more about your home network.

What type of internet connectivity do you have?

A. DSL
B. Cable
C. Other, please specify:____

Question 9: What's your provider's name? :____

Question 10: How much do you pay for internet per month?

A. <$60
B. >$60
C. I don't know

Question 11: What type of network do you have?

A. Wired
B. Wireless
C. Both
D. I don't know

Question 12: What's your network speed? (Marshini will help you with this one ☺)

Upload speed: ____

Download speed: ____

Ping:____

A.3 Kermit Post-Study Survey

Post-Study Survey

Thank you for participating in the Kermit study. In this survey, we would like you to answer some questions about your experience with Kermit. Please answer the questions as best as you can. If you have any questions, please call Marshini Chetty on 404-384-9508 or email marshini@cc.gatech.edu.

Instructions: For each statement, read the statement and then circle the option that best describes how you feel about the statement. If you have any questions or do not understand the statement, feel free to ask the researcher to explain.					
	Strongly Disagree		**Neutral**		**Strongly Agree**
1. I do not mind others in this house knowing when I am online	[1]	[2]	[3]	[4]	[5]
2. I feel like Kermit should have a password control	[1]	[2]	[3]	[4]	[5]
3. I feel like I know more about what bandwidth is	[1]	[2]	[3]	[4]	[5]
4. I feel like I know more about my internet speed	[1]	[2]	[3]	[4]	[5]
5. I feel like anyone should be able to limit a computer on the network	[1]	[2]	[3]	[4]	[5]
6. I feel like anyone should be able to prioritize a computer on the network	[1]	[2]	[3]	[4]	[5]
7. I feel like it is useful to be able to limit or prioritize a computer on the network	[1]	[2]	[3]	[4]	[5]
8. Only certain people's traffic should be prioritized	[1]	[2]	[3]	[4]	[5]
9. I like having a picture representing my computer in Kermit	[1]	[2]	[3]	[4]	[5]
10. I like being able to put a status message for my computer in Kermit	[1]	[2]	[3]	[4]	[5]
11. I like seeing everyone that is connected to Kermit	[1]	[2]	[3]	[4]	[5]
12. I like being able to change my computers name on Kermit	[1]	[2]	[3]	[4]	[5]
13. I know who the biggest bandwidth hog in the house is	[1]	[2]	[3]	[4]	[5]
14. I like seeing a history of bandwidth usage over time	[1]	[2]	[3]	[4]	[5]
15. I like being able to access Kermit on any of the home computers	[1]	[2]	[3]	[4]	[5]
16. I would prefer it if Kermit was an appliance like a thermostat or a router with a display	[1]	[2]	[3]	[4]	[5]
17. I feel like I know more about my home computers and my home network	[1]	[2]	[3]	[4]	[5]
18. I think I am paying too much for my internet speed	[1]	[2]	[3]	[4]	[5]
19. I am more aware of how secure my network is after using Kermit	[1]	[2]	[3]	[4]	[5]
20. I would use a tool like Kermit in future	[1]	[2]	[3]	[4]	[5]

Question 2: What did you like about Kermit?

____
____
____
____
____
____

Question 3: What did you dislike about Kermit?

____
____
____
____
____

Question 4: What would you change about Kermit?

____
____
____
____

Question 5: What (if anything) did you learn about bandwidth from the Kermit study?

Question 6: What (if anything) did you learn about your internet speed from the Kermit study?

Question 7: What technology do you most want at home?

Question 8: If you could design a new technology for your home what would it be?

Question 9: Is there anything else you'd like to tell us about your experience with your home network, Kermit or participating in this study?

Thank you for participating in the Kermit study ☺

A.4 Kermit Pre-Study Sketch

Home Network Sketches

1. On the three pieces of paper provided, please your current home network setup, your current audio/visual network setup and your ideal home network setup.
2. Draw all the computing and related equipment on the first piece of paper
3. Draw all the entertainment system equipment on the second piece of paper
4. Draw your ideal home network on the third piece of paper

Date ____________________ Family Name____________________ Participant ________________

Current Audio/Visual Network Sketch

Date ______________________ Family Name______________________ Participant __________________

Current Home Network Sketch

Date ____________________ Family Name____________________ Participant ________________

Ideal Home Network Sketch

A.5 Kermit Post-Study Sketch

Final Speculation Mini-Sketches

Participant Name:____

Date:____

Instructions: Draw whatever comes to mind when you think about answering the following questions. Your ideas will help us refine Kermit and create other home network visual systems. If you have questions, feel free to ask Marshini for help.

Page **1** of **3**

Sketch 1: How would you prefer to represent your internet speed? e.g. a tap with flowing water? (Yes/No) A speed dial like the one in your car? (Yes/No) A traffic light? (Yes/No) Other ideas?

Sketch 2: What else would you like to show about your internet speed?

Sketch 3: How do you prefer to represent your computers bandwidth usage? Thick or thin lines? (Yes/No) Flowing lines? (Yes/No) Little tokens (Yes/No)? Other ideas?

Sketch 4: What else would you show about your computer's bandwidth?

Sketch 5: What else would you show about the computers in your household? e.g. wireless signal strength? (Yes/No) How secure they are? (Yes/No) How often they are used? (Yes/No) How much power they use? (Yes/No)

Sketch 6: What would you change about the way Kermit shows things now?

A.6 Kermit Diary

Examples pages from the 1 week Internet usage diary.

This is

____________________'s

Diary

Date: Saturday 30 May 2009

	I'm using the internet for...										Who am I?								NOTES about internet speed, network problems etc
EXAMPLE	Email	youtube	facebook	reading the news							mum	mary	dad	sue					
06:00 - 06:30																			
06:30 - 07:00																			
07:30 - 08:00																			
08:30 - 09:00																			
09:30 - 10:00																			
10:30 - 11:00																			
11:00 - 11:30																			
11:30 - 12:00																			
12:00 - 12:30																			
12:30 - 13:00																			
13:00 - 13:30																			
13:30 - 14:00																			
14:00 - 14:30																			
14:30 - 15:00																			
15:00 - 15:30																			
15:30 - 16:00																			
16:00 - 16:30			x									x							looking at facebook, and tried to watch a youtube clip but
16:30 - 17:00			x									x							it was choppy so I gave up, not sure why the connection is so
17:00 - 17:30			x									x							bad
17:30 - 18:00																			
18:00 - 18:30																			
18:30 - 19:00	x			x							x								catching up on email and reading the news, router went
19:00 - 19:30	x			x							x								down and I had to reboot it but then it was ok again
19:30 - 20:00	x			x							x								
20:00 - 20:30																			
20:30 - 21:00																			
21:00 - 21:30																			
21:30 - 22:00																			
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03:30 - 04:00																			
04:00 - 04:30																			
04:30 - 05:00																			
05:30 - 06:00																			

A.7 *Semi-Structured Interview Guiding Questions*

Semi-structured Guiding Interview Questions for Kermit Study

	Network Habits	
	Who is in charge of digital housekeeping?	
	Who set up the home network?	
	Who fixes problems when they occur?	
	Do you ever call friends/family for help? When/who?	
	To each person:	
	Would you fix a problem? What type? When?	
	Would you add/remove devices? Why/Why not?	
	Ever notice internet slowing down? When? Why do you think that is?	
	Ever wondered if someone was hogging the bandwidth?	
	Ever wondered about the speed you're getting from the provider?	
	Do you know what speed you're supposed to be getting?	
	Have you heard of net neutrality? [Explain if not.] What would you think of it?	
	Do you work at home or do homework at home? What types of things do you usually do at home on the net?	
	Where do you place equipment and why?	
	Are there restrictions on who uses network and where?	
	Do you sharing computing equipment?	
	What do you do with old unused equipment?	
	How often do you upgrade?	
	What is your newest/oldest device?	
	When was the last time something broke in the network? Describe the incident.	
	Do you backup your data?	

Visit 2: Installation

	Expectations	
	What do you expect to learn from Kermit?	
	Who do you think will use Kermit the most?	
	Who do you think will use Kermit the least?	
	Does it bother you that anyone can see Kermit?	
	Does it bother you that anyone can prioritize or limit someone?	
	Do you have a secure wireless network?	

Visit 3: During Kermit Use

	Kermit Use	
	Have you noticed who the biggest bandwidth hog is?	
	What have you noticed about your ISP speed?	
	Are there bugs with Kermit?	
	Are there any changes in how you do digital housekeeping?	
	Have you changed the pictures or status message? Why? Why not?	
	Have you had any network problems in the last week?	
	Did you notice anyone who was not supposed to be on the network? What did you do to them?	

Visit 4: Uninstall Kermit Visit and Final Visit

	Kermit Usage	
	Do you understand more/less about network speed?	
	Do you understand more/less about bandwidth use within the home?	
	What did you like about Kermit?	
	What did you dislike about Kermit?	
	What did you think about pictures and computers?	
	What did you think about status messages?	
	When did you use Kermit?	
	Would you prefer to view Kermit on a central display?	
	What did you think about looking at Kermit on your computer display?	
	Did you look at the history view?	
	What do you think about net neutrality?	
	Would a tool like this help or hinder you with networking tasks?	
	Would you prefer Kermit to be included with ISP services?	
	What other information would you like from Kermit?	
	What do you think about net neutrality now?	
	What about control for Kermit? Should there be password protection?	
	Should the interface to Kermit be restricted?	
	Were you able to tell what people were doing from the display?	
	Does Kermit give you more or less of an awareness or connection to others in the house?	
	Do you feel Kermit's visualization emphasizes or de-emphasizes activities that occur online compared to other household activities?	
	How does this affect your privacy and internet usage behavior?	
	Would you share other data with others in the home? URLS? Categories of websites? Are you curious about what others in your home are doing? Or what household members outside of the home are doing online?	

	Do you feel more confident about the information shown? This is the same information that you could get off the router. Is this better or worse than that information?	
	Would you prefer the device to be a separate appliance or just be accessible on your computer?	
	Would you prefer it if there was in home messaging or notice-board?	
	Would you prefer Kermit if there were more or less numbers? For example, if Kermit just told you what the source of the problem was or who was causing the slow down? For instance, if Kermit pinpointed the problem as being related to service, someone in the house or the connection?	
	Do you want more or less information about bandwidth and speed? Should different people get different information?	
	Would it be better if there was a set policy for everyone's traffic. For example, what if access for everyone at certain times is restricted, or if everyone gets fair share or someone gets singled out to be limited? For example some policies may be: • equal share for everyone • someone gets priority • someone decides the rules • priorities changed based on time of day/activity/application being used	
	What other factors cause slow downs?	
	How would you redesign Kermit or your home network?	
	Did you like or dislike the visibility? Does it increase or decrease accountability? Is it a bad or a good thing for your home?	
	Should Kermit be an ambient display e.g. glowing clock or router?	
	Did you discuss anything on Kermit with anyone in the house?	
	Have you ever wondered about the 'accuracy' of information?	

A.8 Technical Implementation of Kermit

In this section, I provide details about the technical implementation of Kermit.

A.8.1 Overview

I used a WRT54GL Broadband Wireless-G LinkSys router for the deployment. Specifically, information was pulled from the router by flashing it with DD-WRT [22], a open source firmware. This firmware allows users to collect more information than a standard router interface and also allows for advanced configuration of the router. I then used a plug-in for DD-WRT called RFlowCollector to track all the traffic flowing through the router. All the information collected using this plug-in was logged to a MySQL database and queried using PHP. I coded the front-end of Kermit, using Adobe Flex and the entire application ran as a flash application in a web browser. This method required no modifications to the router and did not duplicate packet processing. Displaying Kermit through a web browser also ensured that the probe would speak to familiar modes of interaction for most household members. Examples of information pulled from the router included:

- All the active clients connected to the router including the hostname, Internet Protocol (IP) address, Media Access Control (MAC) address, no of connections and bandwidth usage.
- All the DHCP clients including hostname, IP and MAC addresses
- All wireless clients including MAC address and wireless signal strength
- Number of bytes flowing upstream and downstream from every machine connected to the router
- Status of devices as offline or online
- Device hostname

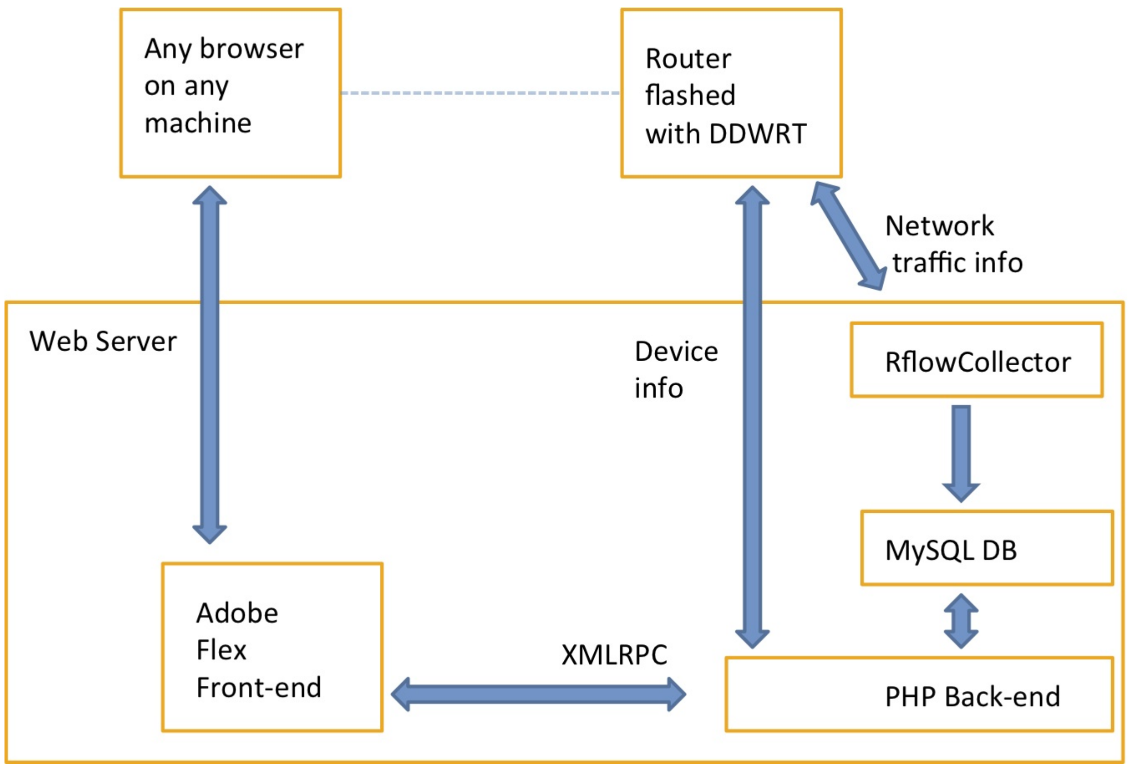

Figure 17: The technical implementation details of Kermit.

A.8.2 Deployment Overview

To set up a Kermit deployment, I used the modified router in combination with a Windows XP laptop on which I installed WAMP web server (which includes support for PHP and MySQL) and RFlowCollector.

Figure 17, illustrates how Kermit is implemented. All the traffic information is passed from the router to RFlowCollector which runs on the laptop. RFlowCollector pushes bandwidth information such as the upload and download bytes going to and coming from each machine to a MySQL database stored on the laptop. A PHP back-end queries the MySQL database and communicates with the Adobe Flex front-end using XMLRPC. The front-end calls various methods that return information from the database and displays this information to the user.

A.8.2.1 Who's Online

A cron job runs on the router and gathers information about the devices that are online at anytime and stores this information in the database. The front-end queries the database every few seconds to get a new list of online devices and updates the display accordingly. Using standard methods to take user input, the front-end passes that information to the back-end to change the machines' names and status messages in the database. Images are uploaded to the back-end using HTTP get and post requests. When devices do not show any traffic activity for a period of 5 minutes, they are grayed out and assumed to be offline. When they become active again, they are displayed again. The back-end only returns a list of active machines to the front-end.

A.8.2.2 Bandwidth Information

The back-end calculates the average upload and download bytes for each machine over the last minute and stores this information in the database. This calculation is updated every minute and allows the GUI to update the interface to reflect the biggest bandwidth user at each minute relative to other users on the network. For the upload and download bytes to each machine shown when a user double-clicks on a device or hovers over a device, this is the average upload and download bytes for that IP address over the last minute, as well as the speed for that machine calculated using the averages over the last minute.

A.8.2.3 Limits and Priorities

When a user is limited or prioritized, this uses a cron script to set an access rule on the router to a priority of 0-3. All access rules are stored in the access table in the MySQL database. All limiting and prioritizing happens by IP address. The access levels offered included: 0 is blocked, 1 is throttled, 2 is normal, and 3 is high priority. However, Kermit only uses options to place machines on high priority or to throttle them. At any time for any machine, only one level is set. Each time a rule for an IP is set, all previous rules are cleared for that computer. In the user interface, a user must explicitly apply or remove a limit or priority to set the corresponding rule on the router.

A.8.2.4 Technical Assumptions and Limitations

The current implementation of Kermit does not account for internal traffic between machines in the network which can also cause Internet slowdowns. For example, if a machine is accessing a shared folder on another machine, this traffic is internal and does not pass through the router. Only the total number of bytes uploaded to and downloaded from the Internet are shown by the plug-in used to gather the data from the router. Kermit did also not make a distinction between whether traffic was encrypted or unencrypted traffic in the display of information. Also, I assumed that the network topology would be such that there would be one router and that all devices would connect to this router without any other hubs or switches in place. I recruited participants with a variety of network topologies and the majority of the participants did not have switches and hubs or multiple access points in their homes.

A.8.2.5 Speed Test and Limitations

For the speed test, on the back-end, the upload test generates a file of around 2 MB (2.5 +/- 0.5MB) and uploads it to a script hosted on an external server. The download test requests a file of around 7 MB (7.5 +/- 0.5 MB) which a remote server generates and streams back to Kermit. At the time of the study, I used a well provisioned server at Georgia Tech to run the tests. If I was to run the tests again, I would use a standard speed test API. My tests were limited in that both the sending and receiving events are done over HTTP which may have affected the results because ISPs may treat this traffic differently to other traffic types. Also, my tests may have been affected by ISPs speeding up initial bursts of traffic because I used a small file size. In my test, the speed is calculated by calculating the total time the HTTP transaction takes, and dividing the total byte size of the file by this time.

A.8.2.6 Privacy

The Kermit database did not store packet headers, the payload of packets or any details about the devices other than the IP and MAC addresses, and host name, along with the bytes uploaded from and downloaded to that machine. No details on internal traffic were collected rather only data on traffic to and from the router was logged.

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